PB87-111746

Waste/Soil Treatability Studies for Four Complex Industrial Wastes: Methodologies and Results Volume 2. Waste Loading Impacts on Soil Degradation, Transformation, and Immobilization

Utah Water Research Lab., Logan

Prepared for

Robert S. Kerr Environmental Research Lab.
Ada, OK

Oct 86

U.S. Department of Commerce
National Technical Information Service
NTIS

PB87-111746

EPA/600/6-86/003b
October 1986

WASTE/SOIL TREATABILITY STUDIES FOR FOUR COMPLEX INDUSTRIAL WASTES: METHODOLOGIES AND RESULTS

Volume 2

Waste Loading Impacts on Soil Degradation, Transformation, and Immobilization

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U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL
INFORMATION SERVICE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA/600/6-86/003b

2.

3. RECIPIENT'S ACCESSION NO.
PB87 111746/AS

4. TITLE AND SUBTITLE
WASTE/SOIL TREATABILITY STUDIES FOR FOUR COMPLEX INDUSTRIAL WASTES: METHODOLOGIES AND RESULTS. Volume 2. Waste Loading Impacts on Soil Degradation, Transformation, and Immobilization

5. REPORT DATE
October 1986

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
R. C. Sims, J. L. Sims, D. L. Sorensen, W. J. Doucette, and L. L. Hastings

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Utah State University
Department of Civil and Environmental Engineering
Utah Water Research Laboratory
Logan, Utah 84322

10. PROGRAM ELEMENT NO.
CBWD1A

11. CONTRACT/GRANT NO.
CR-810979

12. SPONSORING AGENCY NAME AND ADDRESS
Robert S. Kerr Environmental Research Lab. - Ada, OK
U.S. Environmental Protection Agency
Post Office Box 1198
Ada, Oklahoma 74820

13. TYPE OF REPORT AND PERIOD COVERED
Final

14. SPONSORING AGENCY CODE
EPA/600/15

15. SUPPLEMENTARY NOTES
Project Officer: John E. Matthews, FTS: 743-2233.

16. ABSTRACT

This two-volume report presents information pertaining to quantitative evaluation of the soil treatment potential resulting from waste-soil interaction studies for four specific wastes listed under Section 3001 of the Resource Conservation and Recovery Act (RCRA). Volume 1 contains information from literature assessment, waste-soil characterization, and treatability screening studies for each selected waste. Volume 2 contains results from bench-scale waste-soil interaction studies; degradation, transformation, and immobilization data are presented for four specific wastes: API separator sludge, slop oil emulsion solids, pentachlorophenol wood preserving waste, and creosote wood preserving waste. The scope of the study involved assessment of the potential for treatment of these hazardous wastes using soil as the treatment medium.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT
RELEASE TO PUBLIC.

19. SECURITY CLASS (This Report)
UNCLASSIFIED

20. SECURITY CLASS (This page)
UNCLASSIFIED

21. NO. OF PAGES
254

22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

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The information in this document has been funded wholly or in part by the United States Environmental Protection Agency under Cooperative Agreement CR-810979 to Utah State University. It has been subjected to the Agency's peer and administrative review, and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

EPA is charged by Congress to protect the Nation's land, air and water systems. Under a mandate of national environmental laws focused on air and water quality, solid waste management and the control of toxic substances, pesticides, noise and radiation, the Agency strives to formulate and implement actions which lead to a compatible balance between human activities and the ability of natural systems to support and nurture life.

The Robert S. Kerr Environmental Research Laboratory is the Agency's center of expertise for investigation of the soil and subsurface environment. Personnel at the Laboratory are responsible for management of research programs to: (a) determine the fate, transport and transformation rates of pollutants in the soil, the unsaturated and the saturated zones of the subsurface environment; (b) define the processes to be used in characterizing the soil and subsurface environment as a receptor of pollutants; (c) develop techniques for predicting the effect of pollutants on ground water, soil, and indigenous organisms; and (d) define and demonstrate the applicability and limitations of using natural processes, indigenous to the soil and subsurface environment, for the protection of this resource.

When applicable, enviromentally acceptable treatment of hazardous waste in soil systems is a function of operation and management practices at a given site. Successful operation and management practices are dependent on identifying waste loading constraints for that particular site. There is currently a lack of readily available information relative to impact of waste loading rates and frequencies on transformation and transport of hazardous organic constituents in waste-soil matrices and to methodologies for making such determinations. This two-volume report is intended to propose one set of methodologies for determining waste loading constraints for soil systems and to provide an assessment of data collected using the proposed set of methodologies for two petroleum refining and two wood preserving waste streams applied to two soil types. Volume 1 contains results from literature assessment, waste/soil characterization and treatability screening studies; Volume 2 contains results from bench-scale degradation, transformation and immobilization studies.

Clinton W. Hall

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Director
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ABSTRACT

This is Volume 2 of a two-volume report that presents information pertaining to quantitative evaluation of the soil treatment potential resulting from waste-soil interaction studies for four wastes listed under Section 3001 of the Resource Conservation and Recovery Act (RCRA). This volume contains information from bench-scale waste-soil interaction studies. Treatment information, including degradation, transformation, and immobilization data for hazardous constituents are presented. The four wastes included API separator sludge, slop oil emulsion solids, pentachlorophenol wood preserving waste, and creosote wood preserving waste. Chemical analyses and bioassays were used to characterize and quantify treatment potential for soil-waste mixtures.

Objectives of the research reported in this volume were to:

(1) Develop degradation, transformation, and immobilization information for each candidate hazardous waste in two experimental soils.

(2) Develop methodologies for measurement of "volatilization-corrected" degradation rates and partition coefficients; use the methodologies developed to generate degradation kinetics/partition coefficients for a subset of waste-soil combinations and for a subset of constituents common to all wastes.

Specific results and conclusions based on the objectives include:

(1) Polynuclear aromatic hydrocarbon (PAH) constituents were degraded in all four wastes under conditions of initial waste application to nonacclimated soils as well as when wastes were reapplied to soils. Generally an increase in PAH half-life was correlated with increasing molecular weight or compound size.

(2) Pentachlorophenol degradation rate in PCP wood preserving waste appeared to be related to the initial loading rate and the loading rate used when the waste was reapplied. Higher initial rates and reapplication rates resulted in higher half-life values.

(3) All waste-soil mixtures exhibited an initial increase in water soluble fraction (WSF) toxicity followed by a decrease in toxicity with incubation time. The pattern of WSF toxicity with time was considered to be an indication of formation and degradation of toxic intermediates.

(4) Results for mutagenicity evaluations for detoxification of soil-waste mixtures were dependent upon waste loading rate, waste type, and soil type.

(5) Partition coefficients determined for PAH and volatile constituents contained in each of the waste evaluated demonstrated highest partitioning of constituents into the waste (oil) phase. Relative concentrations between water and waste (oil) phases for PAH constituents were 1:1000 to 1:100,000, with the higher ratios observed for the petroleum wastes. Relative concentrations among air:water:waste (oil) phases for VOCs were generally 1:100:100,000.

Information concerning "volatilization-corrected" degradation rates in soils and partition coefficients provided input to the proposed U.S. EPA Regulatory and Investigative Treatment Zone (RITZ) model developed to assess treatment potential for organic constituents in soil.

Results of the waste-soil treatability studies indicate the importance of loading rate, site (soil) selection, and site management for treatment of hazardous constituents in soil systems.

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ACKNOWLEDGMENTS

Chemical and biological analyses and quality control aspects for the large volume of samples generated in this research project were performed by research technicians Mr. Michael Walsh (Chemist), Mr. Robert Bramblett (Biologist), and Ms. Kerri Sales (Chemist) of the Toxic and Hazardous Waste Management Group at the Utah Water Research Laboratory. Environmental Engineering graduate students who assisted in analytical methods development included Mr. Mervin Coover, Mr. Kapsong Park, and Mr. Ai-He Zhou.

SECTION 1

INTRODUCTION

Treatment of hazardous waste in soil systems offers a potentially attractive alternative for management of wastes containing selected hazardous organic constituents; however, use of this alternative must be restricted to those wastes for which degradation, transformation, and immobilization of such constituents can be acceptably demonstrated. This research project was designed to evaluate the potential for treatment in soil (degradation, transformation, and immobilization) of four listed hazardous wastes as a function of waste loading, soil type, and soil moisture content. The four hazardous wastes included API separator sludge, slop oil emulsion solids, creosote wood preserving waste, and pentachlorophenol wood preserving waste.

Specific objectives of this research project were to:

(1) Conduct a literature assessment for each candidate hazardous waste, API separator sludge, slop oil emulsion solids, creosote wood preserving waste, and pentachlorophenol (PCP) wood preserving waste to obtain specific land treatability information, i.e., degradation, transformation, and immobilization, for hazardous constituents identified in each waste.

(2) Characterize candidate wastes for identification of specific constituents of concern; and characterize experimental soils for assessment of specific parameters that influence land treatability potential.

(3) Conduct treatability screening experiments using a battery of microbial assays to determine waste loading rates (mg waste/kg soil) to be used in subsequent experiments to assess potential for treatment.

(4) Develop degradation, transformation, and immobilization information as a function of loading for each candidate hazardous waste in the soil types.

(5) Develop methodologies for the measurement of "volatilization-corrected" degradation rates and for measurement of partition coefficients; use methodologies developed to generate degradation kinetics/partition coefficients for a subset of soil/waste combinations and for constituents common to all candidate wastes.

Information generated relative to the last two objectives is presented in this volume (Volume 2) of the project report. This information combined with the information presented in Volume 1 provide an approach for evaluating waste-soil interactions, i.e., soil treatability potential, for hazardous wastes. The combined information also provides a comprehensive assessment for treatability of the four candidate hazardous wastes in soil.

SECTION 2

CONCLUSIONS

Specific conclusions based on project objectives and research results presented in Volume 2 include:

(1) It was possible to characterize treatment in soil systems in terms of degradation, transformation, and immobilization of hazardous wastes constituents using the methodology and procedures described in this report.

(2) The methodology developed for the measurement of "volatilization-corrected" degradation rates in soil systems for hazardous constituents in the four wastes evaluated allowed more accurate evaluation of degradation as a treatment mechanism.

(3) The methodology developed for the measurement of partition coefficients for hazardous constituents in the four wastes among waste, water, soil, and air phases was useful for obtaining partition coefficients for waste (oil)/water (K_o), air/water (K_h), and air/waste (K_{oa}), for volatile constituents and for waste (oil)/water for semivolatile constituents.

(4) PAH constituents contained in the four wastes investigated were degraded under conditions of initial waste application to nonacclimated soils as well as when wastes were reapplied to soils. In general, PAH degradation did not appear to be influenced by soil type. Soil degradation of PAH compounds in petroleum refinery wastes generally exhibited higher rates than for wood preserving wastes.

(5) Degradation rates for some PAH constituents present in complex wastes evaluated in this project were generally higher than degradation rates which have been reported for single PAH compounds and synthetic mixtures of PAH compounds incubated in different soils (Sims 1982).

(6) Water soluble fraction (WSF) toxicity for soil-waste mixtures generally exhibited an increase followed by a decrease in toxicity with incubation time. This pattern of WSF toxicity with time is an indication of the formation and degradation of toxic intermediates, i.e., transformation of the wastes.

(7) Results of mutagenicity evaluations for detoxification of petroleum wastes indicated a reduction from mutagenic to nonmutagenic activity with treatment time for API separator sludge in Durant clay loam soil and for slop oil emulsion solids incubated in Durant clay loam and in Kidman sandy loam soils. Wood preserving wastes, however, were not rendered nonmutagenic after 400 days of soil incubation in Durant clay loam soil at waste loading rates of 1.3 percent and 0.7 percent for creosote and PCP wastes, respectively. However, no mutagenicity was detected at a loading rate of 0.3 percent PCP waste in Kidman sandy loam soil, and the initial positive mutagenic potential for a loading rate of 1.0 percent creosote waste was reduced to a nonmutagenic level with a treatment time of 400 days.

(8) Laboratory column leachates from petroleum wastes incubated at the high loading rates in Durant clay loam soil and in Kidman sandy loam soil exhibited little toxicity as measured by the Microtox assay. Leachates produced in creosote and PCP loaded columns exhibited Microtox toxicity, and indicated the potential for generation of WSF extract toxicity that should be considered when determining waste loading rates for the experimental soils used.

(9) Partition coefficients that were determined for PAH and volatile constituents in all four wastes indicated highest partitioning of constituents into the oil (waste) phase. Relative concentrations between water and oil (waste) phases for PAH constituents were generally 1:1000 to 1:100,000, with the higher ratios observed for the petroleum wastes. Relative concentrations among air:water:waste (oil) phases for volatile constituents were generally 1:100:100,000.

(10) Pentachlorophenol degradation rate in PCP wood preserving waste appeared to be related to the initial loading rate and the loading rate used when the waste was reapplied. Higher initial rates and reapplication rates resulted in higher half-life values.

SECTION 3

RECOMMENDATIONS

Based on results of the research investigation described in Volume 2 of this report, the following recommendations are made concerning laboratory treatability studies and treatability of the four hazardous wastes evaluated in this project:

(1) Careful attention in future studies should be given to the potential mutagenicity and fate in soil of intermediate products formed during the degradation processes (transformation). Information obtained concerning the degradation and immobilization of information should be used to aid in selecting loading rates that are used in field-plot studies.

(2) The use of chemical analyses alone appears to be insufficient to characterize treatability of a hazardous waste; therefore, it is recommended that bioassays be used to characterize transformation and immobilization processes to complement chemical analyses information. The use of chemical analyses alone fails to account for interactions of components in a waste and the production of mutagenic metabolites.

(3) When determining partition coefficients (K_o, K_h, K_D, K_{ao}) for evaluation of immobilization processes in waste/soil mixtures, several different ratios of waste:water volumes and several waste:soil weights should be used to generate partition isotherms with several points in order to evaluate the ranges of linearity for the isotherm and partition coefficient values. Determination of partition coefficients between soil and water (K_D) will require larger amounts of waste and water than used in this investigation.

(4) Treatability studies should be conducted at loading rate(s) selected for use at field-pilot and/or full scale facilities. This approach is especially important for evaluation of transformation processes using bioassays, as waste loading rate appears to influence bioassay response for soil-waste mixtures.

(5) Recommended loading rates (waste wet weight/soil dry weight) for field scale evaluations for the wastes addressed in this project based on results of the laboratory treatability studies are listed below for the Durant clay loam soil and Kidman sandy loam soil, respectively: API separator sludge, 6, 6; slop oil emulsion solids, 6, 6; creosote wood preserving waste, 0.7, 0.4; and pentachlorophenol wood preserving waste, 0.3, 0.075.

SECTION 4

WASTE DEGRADATION EVALUATION

INTRODUCTION

Demonstration of degradation of waste and waste constituents is based on the loss of parent compounds within the soil/waste matrix. Complete degradation is the term used to describe the process whereby waste constituents are mineralized to inorganic end products, generally including carbon dioxide, water, and inorganic species of nitrogen, phosphorus, and sulfur. The rate of degradation may be established by measuring the loss of the parent compound from the soil/waste matrix with time.

The role of chemical volatilization in influencing the total loss of parent compound from a soil/waste mixture may be evaluated for obtaining a closer approximation to "bio-" degradation. High volatilization rates for individual chemicals in a complex waste may result in high "apparent" loss rates, which may describe the transfer from soil to air media rather than loss due to biodegradation. The proposed land treatment model uses "volatilization-corrected biodegradation." Therefore, experiments were conducted for evaluating the volatilization potential of a subset of aromatic hazardous constituents in the wastes.

Rates of degradation, based on first order kinetics, were transformed into half-life values for PAH compounds. The half-life values calculated were used for evaluating the effect of waste type, soil type, initial loading rate, and reapplication of waste to soil on the effectiveness of treatment based on degradation. The statistical significance of the slope of the relationship between residual soil concentration and time of treatment (slope significantly different from zero) was used to test the hypothesis that treatment was achieved for each waste/soil combination.

The Petroleum Association for Conservation of the Environment (PACE), Ontario, Canada, made the following observations concerning PAH degradation and petroleum refining wastes.

> Studies using oily wastes and soil mixtures are required to adequately assess the persistence of PAHs in oily wastes applied to land. Such a study requires at least triplicate samples and should proceed until the concentration in the soil approach background concentrations. This process may be time consuming requiring greater than one year, but extrapolations from data collected early in the incubation period is likely to result in a poor estimate of persistence (Bulman et al. 1985).

The degradation of PAH compounds in oily waste-soil mixtures was evaluated in this laboratory investigation utilizing the approach described above.

MATERIALS AND METHODS

Soil/waste mixtures were prepared, at the loading rates identified in Table 1, and incubated in both wooden soil boxes (3 kg soil, dry-weight) and in 600 ml glass reactors (200 g soil, dry-weight). Soil/waste mixtures were maintained at a moisture content less than -2 bars in the wooden soil boxes and at -1/3 bar for Kidman sandy loam soil and -1 bar for Durant clay loam soil in the glass beakers by adding distilled water. All soil-waste mixtures were incubated in constant temperature rooms at 20°C ± 2, and in the dark to prevent photodegradation of organic constituents. Extractions of soil-waste mixtures were conducted through time. Method 8310 (U.S. EPA 1982) was used for pentachlorophenol waste to obtain base/neutral and acid fractions, and a modified Method 8310 (U.S. EPA 1982) (methylene chloride extraction of the soil/waste mixture at neutral pH) was used for the other wastes evaluated. A Tekmar Tissumizer was used to extract residual individual organic constituents from the soil/waste mixture (U.S. EPA 1982, Sims 1982). The procedure for extraction and analysis used is given below.

Sample Extraction

1. Soil (10 g) at 80 percent field capacity is placed in a 600 ml glass beaker or flask.

2. Methylene chloride (250 ml) is added to sample container.

3. The solvent-soil system is homogenized for two minutes with a Tekmar Tissue Homogenizer or equivalent.

4. The methylene chloride extract is decanted.

5. The extract is poured through a drying column containing 3-4 inches of anhydrous sodium sulfate, and collected in a 500 ml Kuderna-Danish (K-D) flask equipped with a 10 ml concentrator tube. The column is rinsed with 50 ml of methylene chloride to complete the quantitative transfer.

6. Clean boiling chips (1-2) are added to the flask and a three-ball Snyder column is attached. The Snyder column is prewetted by adding about 1 ml of methylene chloride to the top. The K-D apparatus is placed on a hot water bath (60-65°C) so that the concentrator tube is partially immersed in the hot water, and the entire lower rounded surface of the flask is bathed in vapor. The equipment is adjusted as necessary to complete the concentration in 15 to 20 minutes. When the apparatus volume of liquid reaches 1 ml, the K-D apparatus is removed and allowed to drain for at least 10 minutes while cooling. The Snyder column is removed and the flask and its lower joint are rinsed into the concentrator tube with 1 to 2 ml of methylene chloride.

TABLE 1. SOIL LOADING RATES FOR HAZARDOUS WASTES

Waste	Loading Rates					
	Kidman Sandy Loam			Durant Clay Loam		
	Low	Medium	High	Low	Medium	High
	(% waste wet weight/soil dry weight)					
Creosote	0.4	0.7	1.0	0.7	1.0	1.3
Pentachlorophenol	0.075	0.15	0.3	0.3	0.5	0.7
API Separator Sludge	6	9	12	6	9	12
Slop Oil	6	8	12	8	12	14

High Performance Liquid Chromatography (HPLC) For Analysis

1. To the extract in the concentrator tube, 4 ml acetonitrile are added with a new boiling chip. The temperature of the hot water bath is increased to 95 to 100°C. The solvent is concentrated as above. After cooling the column is removed and its lower joint is rinsed into the concentrator tube with about 0.2 ml of acetonitrile. The extract volume is adjusted to 1.0 ml to 5.0 ml.

2. The sample extract (3 μl) is injected with a sample injection loop, and integrator set at attenuation of 32. The resulting peak size is recorded in area units.

3. If the peak area exceeds the linear range of the system, the extract is diluted and reanalyzed.

Chromatograph conditions were as follows: isocratic for 1 minute with acetonitrile/water (40/60), linear gradient elution to 100 percent acetonitrile over 7 minutes, followed by a 3-minute hold at 100 percent acetonitrile.

Calculations

The concentration of individual compounds is determined according to the formula:

$$\text{Concentration, mg/kg} = \frac{(A)\ (B)\ (V_t)}{(V_i)\ (W_s)}$$

where

A = Calibration factor for chromatographic system in milligrams per unit area

B = Peak size in injection of sample extract, in area units

V_i = Volume of extract injected (μl)

V_t = Volume of extract total (μl)

W_s = Weight of the soil (dry) (kg)

Volatilization Analysis

The experimental apparatus for volatilization measurements is shown in Figure 1. The system consists of the 500 ml erlenmeyer flask with a fitted glass aeration cap through which high quality breathing air enters the flask through Teflon tubing. The purge air flows over the surface of the soil-waste mixture contained within the flask and exits the aeration cap through an effluent tube close to the top of the flask. The flow path and configuration of the flask ensures effective mixing over the surface of the soil. Effluent purge gas containing volatile constituents from the soil-waste mixture leaves the flask through the Teflon tubing, passes a glass T used for split stream

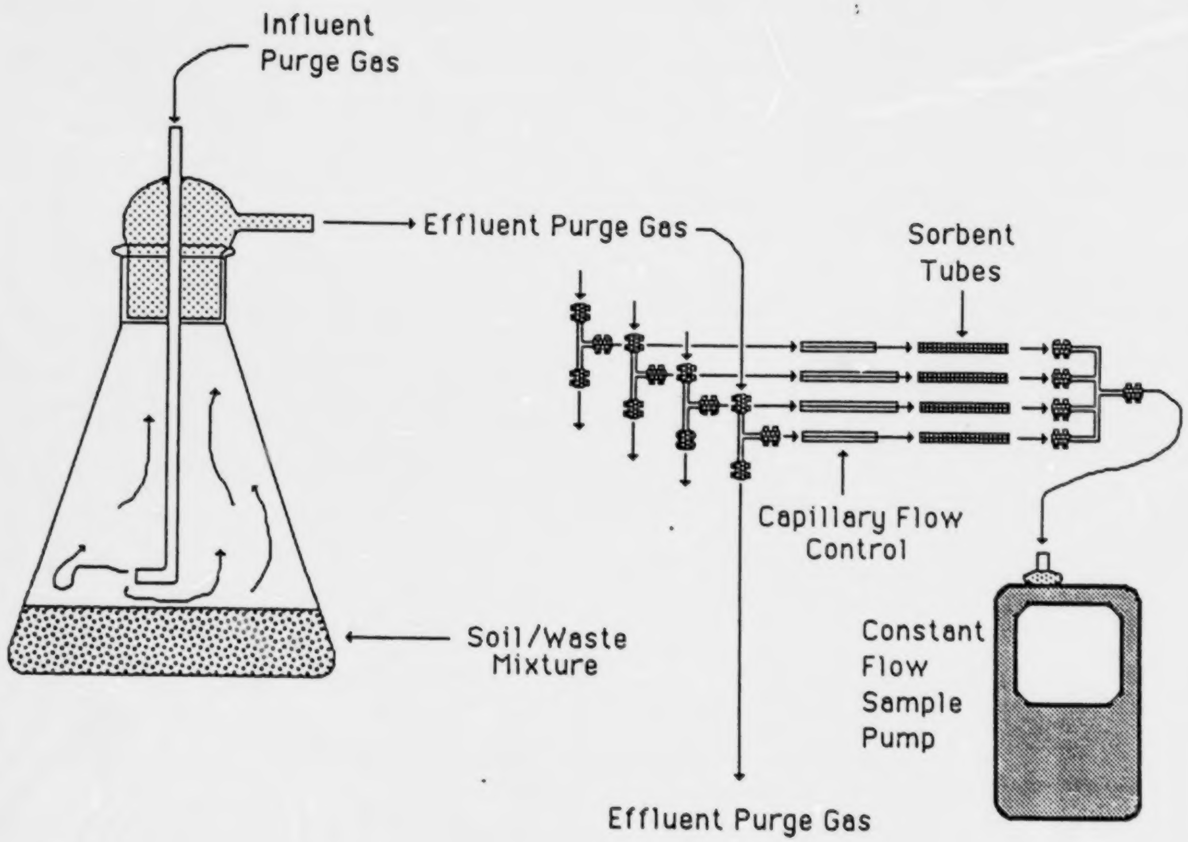
Influent
Purge Gas
Effluent Purge Gas
Sorbent
Tubes
Capillary Flow
Control
Soil/Waste
Mixture
Constant
Flow
Sample
Pump
Effluent Purge Gas

Figure 1. Laboratory flask apparatus used for mass balance measurements.

sampling, and is then carried to a vent for discharge away from the experimental area. Split stream sampling is conducted through the glass Ts in the flask effluent line by using a constant volume sample pump to pull air through Tenax sorbent traps connected to the pump via a balanced, capillary flow controlled glass and Teflon sampling manifold.

The experimental procedure for determining volatilization rates of individual organic constituents, and for correcting apparent loss to obtain loss due to biodegradation is given below.

Experimental Procedure for Volatilization Measurements

a. An experimental run is initiated by first placing 200 gm of soil in experimental flask units. Waste is added to the 200 g of soil in the flask, is quickly mixed, and the flask units are quickly capped.

b. Once capped, the purge gas should be initiated at a controlled rate of 200 ml/min, and initial volatilization measurements should be initiated by drawing a constant volume sample of flask effluent gas through the sorbent traps via a constant volume sample pump and a balanced, capillary flow controlled four-place sampling manifold (three samples plus a blank). This procedure allows the concurrent sampling of all flask units for the same period of time and during the same time period over the volatilization run.

c. Sample pump rate and purge gas flow rate are measured before each sampling event via a bubble tube flow meter, and the duration of the sorbent tube sampling is recorded for accurate emission flux rate calculations.

d. The sorbent traps should generally be sampled at a rate of 100 ml/min/trap for a period not exceeding 5 minutes to minimize breakthrough of the most volatile component of interest. Breakthrough traps are used in at least the first five sampling events to allow the quantification of breakthrough that occurs during this time, and all mass flux values should be calculated with the inclusion of this observed breakthrough mass.

e. Upon completion of the sampling event, the sorbent tubes are placed in muffled culture tubes and stored at 4°C for a maximum of four weeks prior to specific component identification via GC/FID analysis.

f. Sorbent tube desorption is carried out using a Tekmar™ LSD-1 liquid sample concentrator or equivalent that contains a trap heater oven modified for the 5.5 mm O.D., 10 mm long, thin walled stainless steel sorbent tubes recommended for use. Sample tubes are desorbed for four minutes at a temperature of 250°C prior to component separation and identification.

g. The sampling and analysis procedure was repeated at selected time intervals following waste addition corresponding to the anticipated log decay in volatilization rates of volatile organics from the soil systems. A sampling schedule that was followed is as follows:

0, 15 min, 1 hour, 2.5 hour, 10 hour, 1 day, 2 days

If results indicated undetectable air emission levels after 2 days of sampling, the air emission portion of the study was terminated. If blank soils showed insignificant contamination within the first day of sampling, their use was discontinued. Blank and spike traps were used throughout the sampling period, however, to obtain QA/QC information for the method.

h. One flask from each loading rate was sacrificed periodically and chemically extracted to allow correlation with the degradation studies evaluated in the soil boxes and 600 ml glass reactors regarding residual levels of contaminants of concern in the soil:waste mixture.

Data Calculations

An initial emission mass flux rate is calculated (mass/area/time) along with a first order emission rate constant and a half-life for volatilization ($t_{1/2}$ in days) representing the time for emission rates to be reduced to one-half their initial values.

A plot of cumulative mass of organic constituent, collected in the flask effluent gas versus time is made. These cumulative mass values are used to correct degradation data for volatile emission losses by subtracting them from the total mass change as indicated from beaker degradation studies. Measured emission rates (mass/area/time) as a function of time are then plotted based on the soil surface area exposed to the purge air, the fraction of purge air actually sampled through the traps, and the cumulative time during effluent sampling. These effluent emission data can be plotted as described for the degradation data to determine a volatilization half-life. For the PAH compounds addressed in this study no emission data could be calculated since the mass of material in emissions collected was too low to be quantified.

Statistical Evaluation

Statistical methods were used to help determine estimates of compound half-lives and confidence intervals for individual compounds. Differences in concentrations of PAH compounds and PCP between sampling times were evaluated by calculating a linear regression based on first order kinetics. The slope of the regression line was used to determine the first order degradation rates for PAH compounds in the waste-soil mixtures. The half-life of each compound was calculated from the first order degradation rate. The half-life values for the lower and upper 95 percent confidence intervals were also calculated for PAH compounds when waste was reapplied to soil to indicate the range of values about the half-life.

If the slope of the first-order regression was nonnegative, indicating that no treatment by degradation was observed, or if degradation could not be quantified due to initial low concentrations (near or below detection limits), no degradation information is reported in the tables. Specific information concerning changes in concentrations with time are given in Appendix A. All of the statistical procedures used were performed using the SPSS computerized statistical package (SPSS Inc. 1986).

RESULTS AND DISCUSSION

A series of experiments were conducted to evaluate the PAH extraction procedure using the Tekmar Tissumizer. Results for spiked recoveries of the 16 priority pollutant PAH compounds for the Durant clay loam and Kidman sandy loam soils are presented in Table 2. Four concentration levels were used in order to bracket the range of PAH concentrations in the soil/waste mixtures from initial concentration (high) to the termination of the degradation experiments (low).

The information presented in Table 2 indicates consistent and generally high recoveries of all 16 PAH compounds from both soil types. Also, recoveries did not vary greatly and were high through a three-log change in PAH concentrations in the experimental soils. Thus the soil extraction procedure used appears to provide consistent and high extraction efficiencies for both soils over the range of concentrations of concern.

Waste degradation results for the four wastes in Durant clay loam soil are summarized in Tables 3 through 14. Tables 3 through 6 summarize degradation rates at low soil moisture (-2 to -4 bars) over approximately 280 days. Tables 7 through 14 summarize degradation rates at high soil moisture (-1/3 to -1 bar) over approximately 100 days. Some samples received a reapplication of waste, as indicated in the tables. Degradation kinetics are expressed as first order reaction rates (per day) and as half-lives (days) for each waste-soil mixture and loading rate evaluated.

Results generally indicate an increase in PAH half-life with increasing molecular weight or compound size. This observation is generally consistent with results obtained for the PAH class of compounds in soil systems (Sims and Overcash 1983). However, half-lives for some higher molecular weight PAH compounds are observed to be lower in these wastes than for half-lives obtained with PAH compounds only, i.e., without the waste matrix (U.S. EPA 1982, Sims 1982). The observed variation in degradation rates and half-lives obtained for the waste constituents may be due to the difficulty in accurately analyzing individual constituents in soil mixed with complex environmental mixtures.

An increase in soil moisture content from -2 to -4 bars to -1/3 and -1 bars generally was associated with a decrease in PAH compound half-life.

Results also indicate that for each petroleum waste the half-life values were similar for some compounds even though the waste loading rate changed. These results would be expected if degradation followed first order kinetics.

PAH constituents in wood preserving wastes exhibited different half-life trends in creosote waste (Tables 5 and 11) compared with PCP waste (Tables 6 and 13). Half-life values were generally higher for the creosote waste, while values for the PCP waste were more typical of those observed for the petroleum refinery wastes.

Half-life values for some waste constituents in each wood preserving waste were similar even though the loading rate changed. These results are

TABLE 2. TISSUMIZER EXTRACTION RECOVERY RESULTS FOR PAH COMPOUNDS IN KIDMAN AND DURANT SOILS*

Compound	Kidman Sandy Loam Soil Concentration in mg/kg				Durant Clay Loam Soil Concentration in mg/kg			
	1000	100	10	1	1000	100	10	1
Naphthalene	92.3 (3.8)	96.0 (0.0)	86.3 (14.6)	-	99.0 (3.0)	111.7 (5.0)	158.3 (8.1)	-
Acenaphthalene	89.7 (4.7)	82.0 (4.4)	41.7 (25.5)	-	87.3 (7.2)	89.3 (8.1)	78.5 (5.0)	-
Acenaphthene	82.3 (3.2)	80.0 (1.7)	68.7 (3.2)	-	86.7 (3.1)	86.3 (11.2)	77.5 (5.0)	-
Fluorene	98.0 (1.0)	96.7 (0.6)	96.0 (1.7)	103.5 (5.0)	98.7 (0.6)	97.7 (1.5)	94.3 (4.0)	94.5 (7.8)
Phenanthrene	98.7 (1.5)	99.3 (0.6)	99.3 (2.1)	110.0 (0.0)	99.0 (1.0)	99.0 (1.0)	98.7 (2.5)	115.3 (7.2)
Anthracene	98.7 (1.5)	89.3 (1.5)	82.0 (3.0)	57.7 (2.5)	94.3 (7.2)	93.0 (2.7)	86.7 (3.5)	65.0 (5.3)
Fluoranthene	95.0 (2.7)	99.3 (1.2)	97.0 (0.0)	85.3 (2.1)	96.0 (0.0)	100.3 (2.3)	98.7 (1.5)	88.0 (16.5)
Pyrene	106.3 (3.1)	107.7 (0.6)	103.0 (1.0)	73.7 (4.0)	107.0 (2.7)	108.0 (3.6)	105.0 (5.3)	80.0 (24.3)
Benzo(a)anthracene	97.0 (2.0)	97.3 (1.2)	97.3 (2.3)	96.3 (5.1)	97.3 (1.2)	98.7 (1.2)	99.0 (1.7)	100.0 (1.4)
Chrysene	95.6 (1.5)	97.0 (1.0)	96.7 (2.1)	94.7 (3.1)	96.7 (0.6)	86.3 (0.6)	98.0 (1.0)	97.0 (1.7)
Benzo(b)fluoranthene	-	61.0 (0.0)	64.0 (1.0)	87.7 (1.5)	-	61.3 (0.6)	63.3 (1.2)	86.7 (2.1)
Benzo(k)fluoranthene	-	104.0 (1.0)	103.7 (1.5)	105.0 (2.7)	-	104.3 (1.5)	105.0 (2.0)	99.7 (2.5)
Benzo(a)pyrene	-	75.3 (2.5)	66.3 (4.7)	61.7 (3.1)	-	79.3 (0.6)	61.7 (2.1)	68.3 (10.0)
Dibenz(ah)anthracene	-	101.7 (2.1)	103.3 (6.4)	78.0 (8.5)	-	103.3 (3.2)	101.3 (4.0)	86.3 (2.3)
Benzo(ghi)pyrene	-	91.0 (0.0)	90.7 (0.6)	102.0 (2.7)	-	92.7 (1.2)	90.3 (2.5)	111.0 (4.6)
Indeno(1,2,3-cd)pyrene	-	97.0 (1.0)	98.3 (1.5)	100.0 (2.0)	-	98.3 (0.6)	98.3 (1.2)	108.0 (0.0)

*Table values represent average recoveries of triplicate extractions at each loading level with standard deviations in parentheses.

TABLE 3. DEGRADATION KINETIC RESULTS FOR PAH COMPOUNDS IN API SEPARATOR SLUDGE MIXED WITH DURANT CLAY LOAM SOIL AS A FUNCTION OF WASTE LOADING RATE (LOW SOIL MOISTURE)

	6% Loading Rate			12% Loading Rate		
PAH	C_o* (mg/kg)	k (day-1)	$t_{1/2}$ (days)	C_o* (mg/kg)	k (day-1)	$t_{1/2}$ (days)
Naphthalene	40.7	-0.0294	24	66.8	-0.0324	21
Fluorene	+					
Phenanthrene	56.4	-0.0045	160			
Anthracene						
Fluoranthene	340	-0.0018	380			
Pyrene	380	-0.0020	340			
Benzo(a)anthracene	91.4	-0.0005	1300			
Chrysene	55.0	-0.0024	290			
Benzo(b)fluoranthene						
Benzo(k)fluoranthene						
Benzo(a)pyrene						
Benzo(ghi)perylene						
Dibenz(a,h)anthracene						
Indeno(1,2,3-cd)pyrene						

*C_o = initial soil concentration immediately after waste incorporation into soil.
+No data indicate insufficient quantitative information to calculate half-life.

TABLE 4. DEGRADATION KINETIC RESULTS FOR PAH COMPOUNDS IN SLOP OIL EMULSION SOLIDS MIXED WITH DURANT CLAY LOAM SOIL AS A FUNCTION OF WASTE LOADING RATE (LOW SOIL MOISTURE)

	8% Loading Rate			12% Loading Rate			14% Loading Rate		
PAH	C_o* (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)	C_o* (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)	C_o* (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)
Naphthalene	190	-0.0094	74	220	-0.0160	43	460	-0.0014	49
Fluorene	+			73.4	-0.0118	59	86.8	-0.0036	200
Phenanthrene				600	-0.0119	58	470	-0.0017	420
Anthracene				70.0	-0.0152	45	10.0	-0.0303	23
Fluoranthene				2000	-0.0040	180	3300	-0.0013	540
Pyrene							3900	-0.0013	540
Benzo(a)anthracene							390	-0.0008	830
Chrysene							160	-0.0010	670
Benzo(b)fluoranthene									
Benzo(k)fluoranthene									
Benzo(a)pyrene				57.8	-0.0288	24	13.8	-0.0328	21
Benzo(ghi)perylene									
Dibenz(a,h)anthracene									
Indeno(1,2,3-cd)pyrene									

*C_o = initial soil concentration immediately after waste incorporation into soil.
+No data indicate insufficient quantitative information to calculate half-life.

TABLE 5. DEGRADATION KINETIC RESULTS FOR PAH COMPOUNDS IN CREOSOTE WOOD PRESERVING WASTE MIXED WITH DURANT CLAY LOAM SOIL AS A FUNCTION OF WASTE LOADING RATE (LOW SOIL MOISTURE)

PAH	0.7% Loading Rate			1.0% Loading Rate			1.3% Loading Rate		
	C_o* (mg/kg)	k (day-1)	$t_{1/2}$ (days)	C_o* (mg/kg)	k (day-1)	$t_{1/2}$ (days)	C_o* (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)
Naphthalene	+						17.6	-0.0196	35
Fluorene	8.7	-0.0035	200	12	-0.0027	260	16.1	-0.004	200
Phenanthrene	30	-0.0004	2000	43	-0.0045	150	53.3	-0.0038	180
Anthracene	3.5	-0.0104	67	6.5	-0.0034	200	11.3	-0.0079	88
Fluoranthene	27	-0.0007	900	40	-0.0016	430	49.6	-0.0031	220
Pyrene	19	-0.0025	300	32	-0.0009	770	78.4	-0.0033	210
Benzo(a)anthracene	2.6	-0.0074	94	4.0	-0.0097	71	5.3	-0.0042	170
Chrysene	3.1	-0.0089	78	4.1	-0.0002	3000	5.8	-0.0054	130
Benzo(b)fluoranthene	1.2	-0.0103	67	1.8	-0.0006	1200	2.1	-0.0028	250
Benzo(k)fluoranthene	0.8	-0.0104	67	1.2	-0.0108	64	1.7	-0.0006	1000
Benzo(a)pyrene	1.4	-0.0114	61	1.6	-0.0128	54	2.0	-0.0018	390
Benzo(ghi)perylene							0.9	-0.0015	460
Dibenz(a,h)anthracene							1.4	-0.0003	2000
Indeno(1,2,3-cd)pyrene	0.6	-0.0042	170	0.6	-0.0041	170	0.7	-0.0021	330

*C_o = initial soil concentration immediately after waste incorporation into soil.
+No data indicate insufficient quantitative information to calculate half-life.

TABLE 6. DEGRADATION KINETIC RESULTS FOR PAH COMPOUNDS IN PCP WOOD PRESERVING WASTES MIXED WITH DURANT CLAY LOAM SOIL AS A FUNCTION OF WASTE LOADING RATE (LOW SOIL MOISTURE)

	0.3% Loading Rate			0.7% Loading Rate		
PAH	C_o* (mg/kg)	k (day-1)	$t_{1/2}$ (days)	C_o* (mg/kg)	k (day-1)	$t_{1/2}$ (days)
Naphthalene	+					
Fluorene	42.7	-0.0383	18	110	-0.0065	110
Phenanthrene	120	-0.0101	68	340	-0.0022	320
Anthracene	10.0	-0.0279	25	90.1	-0.0011	630
Fluoranthene	110	-0.0063	110			
Pyrene	100	-0.0062	110	350	-0.0019	370
Benzo(a)anthracene				65.4	-0.0013	550
Chrysene				38.1	-0.0017	410
Benzo(b)fluoranthene				53.0	-0.0026	270
Benzo(k)fluoranthene				14.6	-0.0013	520
Benzo(a)pyrene				18.2	-0.0052	130
Benzo(ghi)perylene						
Dibenz(a,h)anthracene						
Indeno(1,2,3-cd)pyrene						

*C_o = initial soil concentration immediately after waste incorporation into soil.

+No data indicate insufficient quantitative information to calculate half-life

TABLE 7. DEGRADATION KINETIC INFORMATION FOR PAH COMPOUNDS IN API SEPARATOR SLUDGE WASTE REAPPLIED TO DURANT CLAY LOAM AT -1 BAR SOIL MOISTURE, EXPERIMENT M/M*

				95% Confidence Interval			
				Lower Limit		Upper Limit	
	C_o+ (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)
Naphthalene	37	-0.0627	11	-0.0924	8	-0.0329	21
Fluorene	17	-0.0169	41	-0.0275	25	-0.0063	110
Phenanthrene	110	-0.0150	46	-0.0190	36	-0.0110	63
Anthracene	16	-0.0077	90	-0.0170	41	0.0015	-#
Fluoranthene	550	-0.0027	260	-0.0100	69	0.0043	-
Pyrene	1800	-0.0136	51	-0.0353	20	0.0080	-
Benzo(a)anthracene	**						
Chrysene	85	-0.0132	53	-0.0222	31	-0.0043	161
Benzo(b)fluoranthene	110	-0.0011	630	-0.0173	40	0.0151	-
Benzo(k)fluoranthene	370	-0.0114	61	-0.0262	26	0.0033	-
Benzo(a)pyrene	170	-0.0066	105	-0.0278	25	0.0147	-
Benzo(ghi)perylene							
Dibenz(a,h)anthracene							
Indeno(1,2,3-cd)pyrene							

*M/M = originally loaded at medium rate (9%), reloaded at medium rate.
+C_o = initial soil concentration immediately after waste incorporation into soil.
#- indicates treatment was not observed, based on slope of first order regression line.
**No data indicate insufficient quantitative information to calculate half-life.

TABLE 8. DEGRADATION KINETIC INFORMATION FOR PAH COMPOUNDS IN API SEPARATOR SLUDGE WASTE REAPPLIED TO DURANT CLAY LOAM AT -1 BAR SOIL MOISTURE, EXPERIMENT H/NR*

				95% Confidence Interval			
				Lower Limit		Upper Limit	
	C_o+ (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)
Naphthalene	#						
Fluorene	20	-0.0305	23	-0.0461	15	-0.0149	47
Phenanthrene	43	-0.0054	128	-0.0170	41	0.0061	-**
Anthracene							
Fluoranthene							
Pyrene							
Benzo(a)anthracene							
Chrysene							
Benzo(b)fluoranthene							
Benzo(k)fluoranthene							
Benzo(a)pyrene							
Benzo(ghi)perylene							
Dibenz(a,h)anthracene							
Indeno(1,2,3-cd)pyrene							

*H/NR = originally loaded at high rate (12%), not reloaded.

+C_c = initial soil concentration immediately after waste incorporation into soil.

#No data indicate insufficient quantitative information to calculate half-life.

**- indicates treatment was not observed, based on slope of first order regression line.

TABLE 9. DEGRADATION KINETIC INFORMATION FOR PAH COMPOUNDS IN SLOP OIL EMULSION SOLIDS REAPPLIED TO DURANT CLAY LOAM AT -1 BAR SOIL MOISTURE, EXPERIMENT M/M*

				95% Confidence Interval			
				Lower Limit		Upper Limit	
	C_o+ (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)
Naphthalene	270	-0.0310	22	-0.0478	14	-0.0141	49
Fluorene	110	-0.0259	27	-0.0510	14	-0.0009	803
Phenanthrene	700	-0.0340	20	-0.0630	11	-0.0043	159
Anthracene	110	-0.0870	8	-0.1440	5	-0.0310	22
Fluoranthene	8300	-0.0392	18	-0.0789	9	0.0005	-#
Pyrene	9100	-0.0339	20	-0.0717	10	0.0039	-
Benzo(a)anthracene	540	-0.0260	27	-0.0595	12	0.0075	-
Chrysene	210	-0.0043	161	-0.0169	41	0.0082	-
Benzo(b)fluoranthene	**						
Benzo(k)fluoranthene	58	-0.0089	78	-0.0360	19	0.0182	-
Benzo(a)pyrene	72	-0.0496	14	-0.0801	9	-0.0190	36
Benzo(ghi)perylene							
Dibenz(a,h)anthracene							
Indeno(1,2,3-cd)pyrene							

*M/M = originally loaded at medium rate (12%), reloaded at medium rate.

+C_o = initial soil concentration immediately after waste incorporation into soil.

#- indicates treatment was not observed, based on slope of first order regression line.

**No data indicate insufficient quantitative information to calculate half-life.

TABLE 10. DEGRADATION KINETIC INFORMATION FOR PAH COMPOUNDS IN SLOP OIL EMULSION SOLIDS REAPPLIED TO DURANT CLAY LOAM AT -1 BAR SOIL MOISTURE, EXPERIMENT H/NR*

				95% Confidence Interval			
				Lower Limit		Upper Limit	
	C_0+ (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)
Naphthalene	29	-0.0187	37	-0.0254	27	-0.0120	58
Fluorene	#						
Phenanthrene	320	-0.0640	11	-0.1390	5	0.0110	-**
Anthracene	60	-0.0320	22	-0.1010	7	0.0370	-
Fluoranthene	11000	-0.0170	41	-0.0390	18	0.0047	-
Pyrene	4500	-0.0157	44	-0.0864	8	0.0549	-
Benzo(a)anthracene	480	-0.0020	347	-0.0135	51	0.0094	-
Chrysene							
Benzo(b)fluoranthene							
Benzo(k)fluoranthene							
Benzo(a)pyrene	55	-0.0076	91	-0.0151	46	-0.0002	3600
Benzo(ghi)perylene							
Dibenz(a,h)anthracene							
Indeno(1,2,3-cd)pyrene							

*H/NR = originally loaded at high rate (14%), not reloaded.

+C_0 = initial soil concentration immediately after waste incorporation into soil.

#No data indicate insufficient quantitative information to calculate half-life.

**- indicates treatment was not observed, based on slope of first order regression line.

TABLE 11. DEGRADATION KINETIC INFORMATION FOR PAH COMPOUNDS IN CREOSOTE WOOD PRESERVING WASTE REAPPLIED TO DURANT CLAY LOAM AT -1 BAR SOIL MOISTURE, EXPERIMENT M/M*

				95% Confidence Interval			
				Lower Limit		Upper Limit	
	C_o+ (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)
Naphthalene	210	-0.1107	6	-0.1107	6	-0.0251	28
Fluorene	44	-0.0008	890	-0.0134	52	0.0119	-#
Phenanthrene	410	-0.0174	40	-0.0257	27	-0.0090	77
Anthracene	85	-0.0020	350	-0.0112	62	0.0072	-
Fluoranthene	**						
Pyrene	300	-0.0001	8000	-0.0071	98	0.0069	-
Benzo(a)anthracene							
Chrysene							
Benzo(b)fluoranthene							
Benzo(k)fluoranthene							
Benzo(a)pyrene							
Benzo(ghi)perylene							
Dibenz(a,h)anthracene							
Indeno(1,2,3-cd)pyrene	6.3	-0.0054	230	-0.0333	21	0.0225	-

*M/M = originally loaded at medium rate (1.0%), reloaded at medium rate.

+C_o = initial soil concentration immediately after waste incorporation into soil.

#- indicates treatment was not observed, based on slope of first order regression line.

**No data indicate insufficient quantitative information to calculate half-life.

TABLE 12. DEGRADATION KINETIC INFORMATION FOR PAH COMPOUNDS IN CREOSOTE WOOD PRESERVING WASTE REAPPLIED TO DURANT CLAY LOAM AT -1 BAR SOIL MOISTURE, EXPERIMENT H/NR*

				95% Confidence Interval			
				Lower Limit		Upper Limit	
	C_o+ (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)
Naphthalene	#						
Fluorene	45	-0.0094	74	-0.0365	19	0.0177	-**
Phenanthrene	110	-0.0100	69	-0.0220	32	0.0008	-
Anthracene	150	-0.0052	134	-0.0120	58	0.0017	-
Fluoranthene	410	-0.0033	210	-0.0255	27	0.0188	-
Pyrene	220	-0.0033	210	-0.0395	18	0.0328	-
Benzo(a)anthracene	43	-0.0014	495	-0.0209	33	0.0182	-
Chrysene	43	-0.0021	330	-0.0215	32	0.0174	-
Benzo(b)fluoranthene	18	-0.0044	158	-0.0250	28	0.0160	-
Benzo(k)fluoranthene							
Benzo(a)pyrene							
Benzo(ghi)perylene							
Dibenz(a,h)anthracene							
Indeno(1,2,3-cd)pyrene							

*H/NR = originally loaded at high rate (1.3%), not reloaded.

+C_o = initial soil concentration immediately after waste incorporation into soil.

#No data indicate insufficient quantitative information to calculate half-life.

**- indicates treatment was not observed, based on slope of first order regression line.

TABLE 13. DEGRADATION KINETIC INFORMATION FOR PAH COMPOUNDS IN PENTACHLOROPHENOL WOOD PRESERVING WASTE REAPPLIED TO DURANT CLAY LOAM AT -1 BAR SOIL MOISTURE, EXPERIMENT M/M*

				95% Confidence Interval			
				Lower Limit		Upper Limit	
	C_0+ (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)
Naphthalene	#						
Fluorene	150	-0.0169	41	-0.0257	27	-0.0081	86
Phenanthrene	600	-0.0240	29	-0.0330	21	-0.0150	46
Anthracene	280	-0.0080	87	-0.0130	53	-0.0027	257
Fluoranthene							
Pyrene	370	-0.0023	301	-0.0057	122	0.0010	-**
Benzo(a)anthracene	29	-0.0097	71	-0.0244	28	0.0050	-
Chrysene	46	-0.0001	9800	-0.0022	315	0.0021	-
Benzo(b)fluoranthene							
Benzo(k)fluoranthene							
Benzo(a)pyrene							
Benzo(ghi)perylene							
Dibenz(a,h)anthracene	2.0	-0.0013	533	-0.0147	47	0.0122	-
Indeno(1,2,3-cd)pyrene							

*M/M = originally loaded at medium rate (0.5%), reloaded at medium rate.

+C_0 = initial soil concentration immediately after waste incorporation into soil.

#No data indicate insufficient quantitative information to calculate half-life.

**- indicates treatment was not observed, based on slope of first order regression line.

TABLE 14. DEGRADATION KINETIC INFORMATION FOR PAH COMPOUNDS IN PENTACHLOROPHENOL WOOD PRESERVING WASTE REAPPLIED TO DURANT CLAY LOAM AT -1 BAR SOIL MOISTURE, EXPERIMENT H/NR*

				95% Confidence Interval			
				Lower Limit		Upper Limit	
	C_o+ (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)
Naphthalene	#						
Fluorene	45	-0.0369	19	-0.0491	14	-0.0247	28
Phenanthrene	110	-0.0150	46	-0.0340	20	0.0048	-**
Anthracene	150	-0.0043	159	-0.0200	35	0.0120	-
Fluoranthene	410	-0.0091	76	-0.0284	24	0.0103	-
Pyrene	220	-0.0134	52	-0.0311	22	0.0043	-
Benzo(a)anthracene	43	-0.0006	1000	-0.0181	38	0.0168	-
Chrysene	26	-0.0036	193	-0.0204	34	0.0131	-
Benzo(b)fluoranthene	12	-0.0022	315	-0.0132	53	0.0087	-
Benzo(k)fluoranthene							
Benzo(a)pyrene							
Benzo(ghi)perylene	1.6	-0.0071	98	-0.1632	4	0.1490	-
Dibenz(a,h)anthracene	1.4	-0.0031	224	-0.0031	224	-0.0031	224
Indeno(1,2,3-cd)pyrene							

*H/NR = originally loaded at high rate (0.7%), not reloaded.

+C_o = initial soil concentration immediately after waste incorporation into soil.

#No data indicate insufficient quantitative information to calculate half-life.

**- indicates treatment was not observed, based on slope of first order regression line.

similar to those observed for the petroleum wastes, and are expected if degradation processes follow first order kinetics.

After the first experimental period of approximately 280 days, wastes were reapplied to the soil according to the following schedule: 1) waste originally loaded at the medium rate was reloaded at the medium loading rate of application to soil (M/M); 2) waste originally loaded at the low rate was reloaded at the high rate (L/H); and 3) nonacclimated soil was loaded at the high rate of waste application (N/H). Results were converted to first order reaction rate constants and half-life values. A subset of soil/waste mixtures for each soil type and waste type was selected for detailed analysis of degradation. The subset chosen was evaluated for approximately an additional 100 days.

Degradation kinetic results for the soil/waste and treatment combinations selected using the Durant clay loam soil are presented in Tables 7 through 14. For the petroleum wastes, reapplication did not appear to change the half-life values for PAH constituents. Neither an inhibiting nor stimulating effect were observed. For the wood preserving wastes, there is no trend that would suggest a change in half-life with reapplication after 200 days.

Waste degradation results for the four wastes in Kidman sandy loam soil are summarized in Tables 15 through 34. Degradation kinetics are expressed as first order reaction rates (per day) and as half-lives (days) for each loading rate evaluated.

PAH degradation results for wastes incubated in Kidman sandy loam soil generally followed the trend observed for waste treatment in the Durant clay loam soil. PAH degradation generally appeared to be influenced by molecular weight or compound ring size. Variation in the data obtained for degradation increased when waste was reloaded (second experimental period).

Pentachlorophenol was evaluated for degradation in PCP waste. Kinetic information is presented in Tables 35 and 36 for PCP waste in Durant clay loam soil and Kidman sandy loam soil, respectively. Half-life values are similar (257 days and 204 days) for PCP initially loaded at the high rate in both soils and not reapplied. An acclimation of Kidman sandy loam soil to PCP may be occurring as indicated by comparing results for N/H and H/NR for Kidman soil in Table 36. Both samples received PCP waste at the high loading rate (0.3%). However, PCP in the sample incubated for 400 days (H/NR) had a half-life of 204 days, while PCP in the sample incubated for 164 days (N/H) has a half-life of 330 days. Evidence for acclimation is also indicated in the sample initially at the low loading rate (0.075%), Table 36, and reloaded at the high rate (0.3%). The half-life for PCP in this soil is 151 days. Acclimation of soil microorganisms to PCP would be expected to result in lower half-life values (faster kinetics) when waste is reapplied.

SUMMARY

PAH constituents of the four wastes investigated were degraded under conditions of initial waste application to nonacclimated soils as well as when

TABLE 15. DEGRADATION KINETIC RESULTS FOR PAH COMPOUNDS IN API SEPARATOR SLUDGE MIXED WITH KIDMAN SANDY LOAM SOIL AS A FUNCTION OF WASTE LOADING RATE (LOW SOIL MOISTURE)

PAH	6% Loading Rate			12% Loading Rate		
	C_o^* (mg/kg)	k (day-1)	$t_{1/2}$ (days)	C_o^* (mg/kg)	k (day-1)	$t_{1/2}$ (days)
Naphthalene	38.4	-0.0307	23	61.3	-0.0337	21
Fluorene	+					
Phenanthrene	50.4	-0.0014	510			
Anthracene						
Fluoranthene	310	-0.0006	1100			
Pyrene	330	-0.0004	1800			
Benzo(a)anthracene	85.9	-0.0003	2100			
Chrysene	21.2	-0.0006	1200			
Benzo(b)fluoranthene						
Benzo(k)fluoranthene						
Benzo(a)pyrene						
Benzo(ghi)perylene						
Dibenz(a,h)anthracene						
Indeno(1,2,3-cd)pyrene				17.0	-0.0112	62

*C_o = initial concentration in soil immediately after waste incorporation into soil.
+No data indicate insufficient quantitative information to calculate half-life

TABLE 16. DEGRADATION KINETIC RESULTS FOR PAH COMPOUNDS IN SLOP OIL EMULSION SOLIDS MIXED WITH KIDMAN SANDY LOAM SOIL AS A FUNCTION OF WASTE LOADING RATE (LOW SOIL MOISTURE)

	8% Loading Rate			12% Loading Rate		
PAH	C_o* (mg/kg)	k (day-1)	$t_{1/2}$ (days)	C_o* (mg/kg)	k (day-1)	$t_{1/2}$ (days)
Naphthalene	150	-0.0101	66	350	-0.0099	70
Fluorene	+			65.0	-0.0055	130
Phenanthrene				360	-0.0014	500
Anthracene	32.9	-0.0028	250			
Fluoranthene				2600	-0.0013	540
Pyrene	4100	-0.0758	9	3000	-0.0011	630
Benzo(a)anthracene	270	-0.0444	16	320	-0.0010	680
Chrysene				130	-0.0013	540
Benzo(b)fluoranthene				72.9	-0.0023	300
Benzo(k)fluoranthene						
Benzo(a)pyrene						
Benzo(ghi)perylene						
Dibenz(a,h)anthracene						
Indeno(1,2,3-cd)pyrene						

*C_o = initial concentration in soil immediately after waste incorporation into soil.
+No data indicate insufficient quantitative information to calculate half-life

TABLE 17. DEGRADATION KINETIC RESULTS FOR PAH COMPOUNDS IN CREOSOTE WOOD PRESERVING WASTE MIXED WITH KIDMAN SANDY LOAM SOIL AS A FUNCTION OF WASTE LOADING RATE (LOW SOIL MOISTURE)

PAH	0.4% Loading Rate			0.7% Loading Rate			1.0% Loading Rate		
	C_o[*] (mg/kg)	k (day-1)	$t_{1/2}$ (days)	C_o[*] (mg/kg)	k (day-1)	$t_{1/2}$ (days)	C_o[*] (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)
Naphthalene	1.4	-[+]		3.7	-0.0159	44			
Fluorene	4.7	-0.0203	30	100	0.0046	150			
Phenanthrene	170	0.0043	160	330	0.0024	290			
Anthracene	1.1	0.0088	79	5.3	0.0037	190			
Fluoranthene	150	0.0038	180	310	0.0022	320			
Pyrene	130	0.0062	110	260	0.0014	500			
Benzo(a)anthracene	1.1	0.0016	430	3.1	0.0084	83			
Chrysene	1.8	0.01	69	3.3	0.0007	990			
Benzo(b)fluoranthene	7.0	0.0068	100	1.4	0.0015	460			
Benzo(k)fluoranthene	6.0	0.007	100	1.3	0.0118	59			
Benzo(a)pyrene	1.2	0.0117	59	1.6	0.0134	52			
Benzo(ghi)perylene	5.6	0.0003	2000	6.3	+ slope	49	0.6	0.0003	2000
Dibenz(a,h)anthracene									
Indeno(1,2,3-cd)pyrene	6.0	0.0043	160	6.0	0.0042	170	0.5	0.0034	2000

[*] C_o = initial soil concentration immediately after waste incorporation into soil.
[+] - indicates treatment was not observed, based on slope of first order regression line.

TABLE 18. DEGRADATION KINETIC RESULTS FOR PAH COMPOUNDS IN PCP WOOD PRESERVING WASTES MIXED WITH KIDMAN SANDY LOAM SOIL AS A FUNCTION OF WASTE LOADING RATE (LOW SOIL MOISTURE)

PAH	0.075% Loading Rate			0.3% Loading Rate		
	C_o* (mg/kg)	k (day-1)	$t_{1/2}$ (days)	C_o* (mg/kg)	k (day-1)	$t_{1/2}$ (days)
Naphthalene	34.7	-0.0339	20	96.7	-0.0012	590
Fluorene	+			20.4	-0.0330	21
Phenanthrene	30.8	-0.0134	52	99.3	-0.0049	140
Anthracene						
Fluoranthene	27.4	-0.0227	190	91.0	-0.0035	200
Pyrene	28.0	-0.0353	20	95.7	-0.0049	140
Benzo(a)anthracene				38.2	-0.0006	1200
Chrysene				9.9	-0.0026	270
Benzo(b)fluoranthene						
Benzo(k)fluoranthene						
Benzo(a)pyrene						
Benzo(ghi)perylene						
Dibenz(a,h)anthracene						
Indeno(1,2,3-cd)pyrene						

*C_o = initial soil concentration immediately after waste incorporation into soil.
+No data indicate insufficient quantitative information to calculate half-life

TABLE 19. DEGRADATION KINETIC INFORMATION FOR PAH COMPOUNDS IN API SEPARATOR SLUDGE WASTE REAPPLIED TO KIDMAN SANDY LOAM AT -1/3 BAR SOIL MOISTURE, EXPERIMENT M/M[*]

				95% Confidence Interval			
				Lower Limit		Upper Limit	
	C_o[+] (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)
Naphthalene	30	-0.0185	37	-0.0224	31	-0.0146	42
Fluorene	15	-0.0139	49	-0.0346	20	0.0069	-[#]
Phenanthrene	120	-0.0019	360	-0.0170	41	0.0130	-
Anthracene	15	-0.0260	27	-0.0520	13	-0.0009	810
Fluoranthene	780	-0.0333	21	-0.0662	10	-0.0004	1634
Pyrene	1000	-0.0553	13	-0.0957	7	-0.0149	47
Benzo(a)anthracene	88	-0.0044	158	-0.0288	24	0.0200	-
Chrysene	160	-0.0011	630	-0.0120	58	0.0097	-
Benzo(b)fluoranthene	[**]						
Benzo(k)fluoranthene	100	-0.0050	139	-0.0209	33	0.0109	-
Benzo(a)pyrene							
Benzo(ghi)perylene							
Dibenz(a,h)anthracene							
Indeno(1,2,3-cd)pyrene							

[*] M/M = originally loaded at medium rate (9%), reloaded at medium rate.

[+] C_o = initial soil concentration immediately after waste incorporation into soil.

[#] - indicates treatment was not observed, based on slope of first order regression line.

[**] No data indicate insufficient quantitative information to calculate half-life.

TABLE 20. DEGRADATION KINETIC INFORMATION FOR PAH COMPOUNDS IN API SEPARATOR SLUDGE WASTE REAPPLIED TO KIDMAN SANDY LOAM AT -1/3 BAR SOIL MOISTURE, EXPERIMENT L/H[*]

				95% Confidence Interval			
				Lower Limit		Upper Limit	
	C_o[+] (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)
Naphthalene	66	-0.0272	25	-0.0320	22	-0.0223	31
Fluorene	32	-0.0022	315	-0.0061	114	0.0017	-[#]
Phenanthrene	190	-0.0010	693	-0.0029	239	0.0009	-
Anthracene	19	-0.0160	43	-0.0650	11	0.0330	-
Fluoranthene	**						
Pyrene	1500	-0.0048	144	-0.0181	38	0.0085	-
Benzo(a)anthracene	380	-0.0009	747	-0.0096	72	0.0078	-
Chrysene	140	-0.0025	277	-0.0122	57	0.0071	-
Benzo(b)fluoranthene							
Benzo(k)fluoranthene							
Benzo(a)pyrene	160	-0.0048	144	-0.0106	65	0.0007	-
Benzo(ghi)perylene							
Dibenz(a,h)anthracene							
Indeno(1,2,3-cd)pyrene	0.3	-0.0660	11	-0.3501	2	0.2181	-

[*] L/H = originally loaded at low rate (6%), reloaded at high rate (12%).

[+] C_o = initial soil concentration immediately after waste incorporation into soil.

[#] - indicates treatment was not observed, based on slope of first order regression line.

[**] No data indicate insufficient quantitative information to calculate half-life.

TABLE 21. DEGRADATION KINETIC INFORMATION FOR PAH COMPOUNDS IN API SEPARATOR SLUDGE WASTE REAPPLIED TO KIDMAN SANDY LOAM AT -1/3 BAR SOIL MOISTURE, EXPERIMENT N/H*

				95% Confidence Interval			
				Lower Limit		Upper Limit	
	C_o+ (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)
Naphthalene	69	-0.0393	18	-0.0476	15	-0.0310	22
Fluorene	21	-0.0009	753	-0.0090	139	0.0031	-#
Phenanthrene	150	-0.0025	277	-0.0038	182	-0.0012	578
Anthracene	20	-0.0140	50	-0.0250	28	-0.0034	204
Fluoranthene	**						
Pyrene							
Benzo(a)anthracene							
Chrysene							
Benzo(b)fluoranthene	370	-0.0115	60	-0.0244	28	0.0014	-
Benzo(k)fluoranthene	240	-0.0095	73	-0.0241	29	0.0051	-
Benzo(a)pyrene							
Benzo(ghi)perylene							
Dibenz(a,h)anthracene							
Indeno(1,2,3-cd)pyrene							

*N/H = nonacclimated soil loaded at high rate (12%).

+C_o = initial soil concentration immediately after waste incorporation into soil.

#- indicates treatment was not observed, based on slope of first order regression line.

**No data indicate insufficient quantitative information to calculate half-life.

TABLE 22. DEGRADATION KINETIC INFORMATION FOR PAH COMPOUNDS IN API SEPARATOR SLUDGE WASTE REAPPLIED TO KIDMAN SANDY LOAM AT -1/3 BAR SOIL MOISTURE, EXPERIMENT H/NR*

				95% Confidence Interval			
				Lower Limit		Upper Limit	
	C_0+ (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)
Naphthalene	#						
Fluorene							
Phenanthrene	72	-0.0007	1000	-0.0035	198	0.0021	-**
Anthracene	5.7	-0.0470	15	-0.0540	13	-0.0410	17
Fluoranthene							
Pyrene							
Benzo(a)anthracene							
Chrysene							
Benzo(b)fluoranthene							
Benzo(k)fluoranthene							
Benzo(a)pyrene	60	-0.0092	75	-0.0187	37	0.0003	-
Benzo(ghi)perylene							
Dibenz(a,h)anthracene							
Indeno(1,2,3-cd)pyrene	2.3	-0.0017	408	-0.0382	18	0.0349	-

*H/NR = originally loaded at high rate (12%), not reloaded.

+C_0 = initial soil concentration immediately after waste incorporation into soil.

#No data indicate insufficient quantitative information to calculate half-life.

**- indicates treatment was not observed, based on slope of first order regression line.

TABLE 23. DEGRADATION KINETIC INFORMATION FOR PAH COMPOUNDS IN SLOP OIL EMULSION SOLIDS REAPPLIED TO KIDMAN SANDY LOAM AT -1/3 BAR SOIL MOISTURE, EXPERIMENT M/M*

				95% Confidence Interval			
				Lower Limit		Upper Limit	
	C_o+ (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)
Naphthalene	160	-0.0215	32	-0.0314	22	-0.0117	59
Fluorene	73	-0.0090	77	-0.0135	51	-0.0045	154
Phenanthrene	740	-0.0001	10500	-0.0140	50	0.130	-#
Anthracene	88	-0.0053	131	-0.049	14	0.038	-
Fluoranthene	27000	-0.023	30	-0.0359	19	-0.0102	68
Pyrene	4500	-0.0036	193	-0.0120	58	0.0048	-
Benzo(a)anthracene	**						
Chrysene							
Benzo(b)fluoranthene							
Benzo(k)fluoranthene							
Benzo(a)pyrene	63	-0.0298	23	-0.0625	11	0.0028	-
Benzo(ghi)perylene							
Dibenz(a,h)anthracene							
Indeno(1,2,3-cd)pyrene							

*M/M = originally loaded at medium rate (8%), reloaded at medium rate.

+C_o = initial soil concentration immediately after waste incorporation into soil.

#- indicates treatment was not observed, based on slope of first order regression line.

**No data indicate insufficient quantitative information to calculate half-life.

TABLE 24. DEGRADATION KINETIC INFORMATION FOR PAH COMPOUNDS IN SLOP OIL EMULSION SOLIDS REAPPLIED TO KIDMAN SANDY LOAM AT -1/3 BAR SOIL MOISTURE, EXPERIMENT L/H*

				95% Confidence Interval			
				Lower Limit		Upper Limit	
	C_o+ (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)
Naphthalene	270	-0.0161	43	-0.0222	31	-0.0100	69
Fluorene	120	-0.0076	91	-0.0126	55	-0.0026	267
Phenanthrene	620	-0.0030	231	-0.0044	158	-0.0017	408
Anthracene	110	-0.0810	9	-0.1160	6	-0.0460	15
Fluoranthene	6000	-0.0093	75	-0.0279	25	0.0093	-#
Pyrene	6500	-0.0052	133	-0.0074	94	-0.003	231
Benzo(a)anthracene	1000	-0.0041	163	-0.0143	48	0.0061	-
Chrysene	220	-0.0077	90	-0.0136	51	-0.0018	385
Benzo(b)fluoranthene	220	-0.0350	20	-0.0652	11	-0.0048	144
Benzo(k)fluoranthene	100	-0.0426	16	-0.0794	9	-0.0057	122
Benzo(a)pyrene	59	-0.0222	31	-0.0623	11	0.0178	-
Benzo(ghi)perylene	**						
Dibenz(a,h)anthracene							
Indeno(1,2,3-cd)pyrene							

*L/H = originally loaded at low rate (6%), reloaded at high rate (12%).

+C_o = initial soil concentration immediately after waste incorporation into soil.

#- indicates treatment was not observed, based on slope of first order regression line.

**No data indicate insufficient quantitative information to calculate half-life.

TABLE 25. DEGRADATION KINETIC INFORMATION FOR PAH COMPOUNDS IN SLOP OIL EMULSION SOLIDS REAPPLIED TO KIDMAN SANDY LOAM AT -1/3 BAR SOIL MOISTURE, EXPERIMENT N/H*

				95% Confidence Interval			
				Lower Limit		Upper Limit	
	C_o+ (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)
Naphthalene	1400	-0.0224	31	-0.0323	21	-0.0126	55
Fluorene	53	-0.0244	28	-0.0489	14	0.0001	-#
Phenanthrene	**						
Anthracene	55	-0.0680	10	-0.1060	7	-0.0310	22
Fluoranthene	8400	-0.0306	23	-0.0552	13	-0.0059	117
Pyrene	1500	-0.0460	15	-0.2034	3	0.1114	-
Benzo(a)anthracene	1600	-0.0204	34	-0.0548	13	0.0141	-
Chrysene							
Benzo(b)fluoranthene							
Benzo(k)fluoranthene							
Benzo(a)pyrene	-	-0.0335	21	-0.1119	6	0.0449	-
Benzo(ghi)perylene							
Dibenz(a,h)anthracene	-	-0.0294	24	-0.0294	24	-0.0294	24
Indeno(1,2,3-cd)pyrene							

*N/H = nonacclimated soil loaded at high rate (12%).

+C_o = initial soil concentration immediately after waste incorporation into soil.

#- indicates treatment was not observed, based on slope of first order regression line.

**No data indicate insufficient quantitative information to calculate half-life.

TABLE 26. DEGRADATION KINETIC INFORMATION FOR PAH COMPOUNDS IN SLOP OIL EMULSION SOLIDS REAPPLIED TO KIDMAN SANDY LOAM AT -1/3 BAR SOIL MOISTURE, EXPERIMENT H/NR*

				95% Confidence Interval			
				Lower Limit		Upper Limit	
	C_o+ (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)
Naphthalene	#						
Fluorene	35	-0.0079	88	-0.0120	58	-0.0038	182
Phenanthrene	270	-0.0040	173	-0.0052	133	-0.0029	239
Anthracene	49	-0.0764	9	-0.0802	9	-0.0726	10
Fluoranthene	2100	-0.0080	87	-0.0160	43	0.00004	-**
Pyrene							
Benzo(a)anthracene	320	-0.0036	193	-0.0288	24	0.0216	-
Chrysene							
Benzo(b)fluoranthene							
Benzo(k)fluoranthene							
Benzo(a)pyrene	48	-0.0779	9	-0.0779	9	-0.0779	9
Benzo(ghi)perylene							
Dibenz(a,h)anthracene							
Indeno(1,2,3-cd)pyrene							

*H/NR = originally loaded at high rate (12%), not reloaded.
+C_o = initial soil concentration immediately after waste incorporation into soil.
#No data indicate insufficient quantitative information to calculate half-life.
**- indicates treatment was not observed, based on slope of first order regression line.

TABLE 27. DEGRADATION KINETIC INFORMATION FOR PAH COMPOUNDS IN CREOSOTE WOOD PRESERVING WASTE REAPPLIED TO KIDMAN SANDY LOAM AT -1/3 BAR SOIL MOISTURE, EXPERIMENT M/M*

				95% Confidence Interval			
				Lower Limit		Upper Limit	
	C_o+ (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)
Naphthalene	320	-0.0737	9	-0.1178	6	-0.0296	23
Fluorene	150	-0.0170	41	-0.0317	22	-0.0022	315
Phenanthrene	730	-0.0120	58	-0.0170	41	-0.0074	93
Anthracene	210	-0.0013	530	-0.0058	120	0.0032	-#
Fluoranthene	**						
Pyrene	560	-0.0054	128	-0.0111	62	0.0003	-
Benzo(a)anthracene	54	-0.0027	260	-0.0068	102	0.0014	-
Chrysene	51	-0.0005	1300	-0.0047	147	0.0036	-
Benzo(b)fluoranthene	21	-0.0039	178	-0.0070	99	-0.0002	3500
Benzo(k)fluoranthene	15	-0.0017	408	-0.0058	119	0.0024	-
Benzo(a)pyrene	14	-0.0023	301	-0.0050	139	0.0004	-
Benzo(ghi)perylene							
Dibenz(a,h)anthracene							
Indeno(1,2,3-cd)pyrene	2.2	-0.0009	763	-0.0051	136	0.0033	-

*M/M = originally loaded at medium rate (0.7%), reloaded at medium rate.
+C_o = initial soil concentration immediately after waste incorporation into soil.
#- indicates treatment was not observed, based on slope of first order regression line.
**No data indicate insufficient quantitative information to calculate half-life.

TABLE 28. DEGRADATION KINETIC INFORMATION FOR PAH COMPOUNDS IN CREOSOTE WOOD PRESERVING WASTE REAPPLIED TO KIDMAN SANDY LOAM AT -1/3 BAR SOIL MOISTURE, EXPERIMENT L/H*

				95% Confidence Interval			
				Lower Limit		Upper Limit	
	C_o+ (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)
Naphthalene	290	-0.0726	10	-0.1146	6	-0.0305	23
Fluorene	150	-0.0220	32	-0.0537	13	0.0097	-#
Phenanthrene	740	-0.0180	39	-0.0330	21	-0.0032	217
Anthracene	200	-0.0035	198	-0.0230	30	0.0160	-
Fluoranthene	550	-0.0128	54	-0.0240	29	-0.0015	462
Pyrene	540	-0.0120	58	-0.0247	28	0.0006	-
Benzo(a)anthracene	51	-0.0074	94	-0.0146	47	-0.0001	7700
Chrysene	48	-0.0070	99	-0.0192	36	0.0052	-
Benzo(b)fluoranthene	20	-0.0078	89	-0.0155	45	-0.0001	4800
Benzo(k)fluoranthene	16	-0.0063	110	-0.0132	53	0.0005	-
Benzo(a)pyrene	15	-0.0111	62	-0.0351	20	0.0129	-
Benzo(ghi)perylene	**						
Dibenz(a,h)anthracene	4.2	-0.0080	87	-0.0192	36	0.0033	-
Indeno(1,2,3-cd)pyrene	2.7	-0.0096	72	-0.0240	29	0.0048	-

*L/H = originally loaded at low rate (0.4%), reloaded at high rate (1.0%).
+C_o = initial soil concentration immediately after waste incorporation into soil.
#- indicates treatment was not observed, based on slope of first order regression line.
**No data indicate insufficient quantitative information to calculate half-life.

TABLE 29. DEGRADATION KINETIC INFORMATION FOR PAH COMPOUNDS IN CREOSOTE WOOD PRESERVING WASTE REAPPLIED TO KIDMAN SANDY LOAM AT -1/3 BAR SOIL MOISTURE, EXPERIMENT N/H*

				95% Confidence Interval			
				Lower Limit		Upper Limit	
	C_o+ (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)
Naphthalene	270	-0.0035	198	-0.0074	94	0.0003	-#
Fluorene	180	-0.0267	26	-0.0338	21	-0.0196	35
Phenanthrene	830	-0.0260	27	-0.0340	20	-0.0180	39
Anthracene	240	-0.0100	69	-0.0150	46	-0.0043	161
Fluoranthene	570	-0.0094	74	-0.0141	49	-0.0046	151
Pyrene	570	-0.0130	53	-0.0159	44	-0.0101	69
Benzo(a)anthracene	53	-0.0085	82	-0.0218	32	0.0048	-
Chrysene	51	-0.0047	148	-0.0071	98	-0.0022	315
Benzo(b)fluoranthene	21	-0.0080	87	-0.0147	47	-0.0013	533
Benzo(k)fluoranthene	**						
Benzo(a)pyrene	13	-0.0046	151	-0.0108	64	0.0015	-
Benzo(ghi)perylene	0.7	-0.0008	863	-0.0095	73	0.0079	-
Dibenz(a,h)anthracene							
Indeno(1,2,3-cd)pyrene	2.1	-0.0021	330	-0.0071	98	0.0029	-

*N/H = nonacclimated soil loaded at high rate (1.0%).

+C_o = initial soil concentration immediately after waste incorporation into soil.

#- indicates treatment was not observed, based on slope of first order regression line.

**No data indicate insufficient quantitative information to calculate half-life.

TABLE 30. DEGRADATION KINETIC INFORMATION FOR PAH COMPOUNDS IN CREOSOTE WOOD PRESERVING WASTE REAPPLIED TO KIDMAN SANDY LOAM AT -1/3 BAR SOIL MOISTURE, EXPERIMENT H/NR*

				95% Confidence Interval			
				Lower Limit		Upper Limit	
	C_o+ (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)
Naphthalene	#						
Fluorene	23	-0.0047	147	-0.0102	68	0.0008	-**
Phenanthrene	11	-0.0120	58	-0.0160	43	-0.0088	79
Anthracene	12	-0.0036	191	-0.0095	73	0.0022	-
Fluoranthene	0.6	-0.0036	191	-0.0091	76	0.0019	-
Pyrene	1.3	-0.0051	136	-0.0103	67	0.0002	-
Benzo(a)anthracene	2.1	-0.0031	224	-0.0092	75	0.0031	-
Chrysene	46	-0.0024	289	-0.0040	173	-0.0007	990
Benzo(b)fluoranthene	30	-0.0072	96	-0.0151	46	0.0006	-
Benzo(k)fluoranthene							
Benzo(a)pyrene							
Benzo(ghi)perylene							
Dibenz(a,h)anthracene							
Indeno(1,2,3-cd)pyrene							

*H/NR = originally loaded at high rate (1.0%), not reloaded.

+C_o = initial soil concentration immediately after waste incorporation into soil.

#No data indicate insufficient quantitative information to calculate half-life.

**- indicates treatment was not observed, based on slope of first order regression line.

TABLE 31. DEGRADATION KINETIC INFORMATION FOR PAH COMPOUNDS IN PENTACHLOROPHENOL WOOD PRESERVING REAPPLIED TO KIDMAN SANDY LOAM AT -1/3 BAR SOIL MOISTURE, EXPERIMENT M/M*

				95% Confidence Interval			
				Lower Limit		Upper Limit	
	C_o+ (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)
Naphthalene	#						
Fluorene	30	-0.0187	37	-0.0359	19	-0.0014	495
Phenanthrene	84	-0.0120	58	-0.0250	29	0.0001	-**
Anthracene							
Fluoranthene	92	-0.0032	217	-0.0189	37	0.0125	-
Pyrene	97	-0.0040	173	-0.0196	35	0.0116	-
Benzo(a)anthracene	10	-0.0057	122	-0.0220	32	0.0105	-
Chrysene	14	-0.0003	2700	-0.0151	46	0.0146	-
Benzo(b)fluoranthene							
Benzo(k)fluoranthene							
Benzo(a)pyrene							
Benzo(ghi)perylene	0.9	-0.0022	315	-0.0089	78	0.0044	-
Dibenz(a,h)anthracene							
Indeno(1,2,3-cd)pyrene							

*M/M = originally loaded at medium rate (0.15%), reloaded at medium rate.

+C_o = initial soil concentration immediately after waste incorporation into soil.

#No data indicate insufficient quantitative information to calculate half-life.

**- indicates treatment was not observed, based on slope of first order regression line.

TABLE 32. DEGRADATION KINETIC INFORMATION FOR PAH COMPOUNDS IN PENTACHLOROPHENOL WOOD PRESERVING WASTE REAPPLIED TO KIDMAN SANDY LOAM AT -1/3 BAR SOIL MOISTURE, EXPERIMENT L/H*

				95% Confidence Interval			
				Lower Limit		Upper Limit	
	C_o^+ (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)
Naphthalene	#						
Fluorene	52	-0.0139	50	-0.0444	16	0.0166	-**
Phenanthrene	130	-0.0120	58	-0.0290	24	0.0049	-
Anthracene							
Fluoranthene	145	-0.0038	182	-0.0083	83	0.0007	-
Pyrene	160	-0.0034	204	-0.0071	98	0.0003	-
Benzo(a)anthracene							
Chrysene	18	-0.0005	1300	-0.0072	96	0.0062	-
Benzo(b)fluoranthene							
Benzo(k)fluoranthene							
Benzo(a)pyrene							
Benzo(ghi)perylene							
Dibenz(a,h)anthracene							
Indeno(1,2,3-cd)pyrene	0.3	-0.0106	65	-0.0318	22	0.0106	-

*L/H = originally loaded at low rate (0.075%), reloaded at high rate (0.3%).

^+C_o = initial soil concentration immediately after waste incorporation into soil.

#No data indicate insufficient quantitative information to calculate half-life.

**- indicates treatment was not observed, based on slope of first order regression line.

TABLE 33. DEGRADATION KINETIC INFORMATION FOR PAH COMPOUNDS IN PENTACHLOROPHENOL WOOD PRESERVING WASTE REAPPLIED TO KIDMAN SANDY LOAM AT -1/3 BAR SOIL MOISTURE, EXPERIMENT N/H*

				95% Confidence Interval			
				Lower Limit		Upper Limit	
	C_o+ (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)
Naphthalene	#						
Fluorene	49	-0.0128	54	-0.0182	38	-0.0074	94
Phenanthrene	120	-0.0150	46	-0.0230	30	-0.0079	88
Anthracene	69	-0.0031	220	-0.0091	76	0.0028	-**
Fluoranthene	110	-0.0015	462	-0.0073	95	0.0043	-
Pyrene	140	-0.0041	169	-0.0095	73	0.0012	-
Benzo(a)anthracene							
Chrysene	21	-0.0028	248	-0.0083	83	0.0027	-
Benzo(b)fluoranthene	8.0	-0.0019	370	-0.0063	109	0.0026	-
Benzo(k)fluoranthene							
Benzo(a)pyrene	4.8	-0.0048	144	-0.0150	46	0.0053	-
Benzo(ghi)perylene							
Dibenz(a,h)anthracene							
Indeno(1,2,3-cd)pyrene							

*N/H = nonacclimated soil loaded at high rate (0.3%).
+C_o = initial soil concentration immediately after waste incorporation into soil.
#No data indicate insufficient quantitative information to calculate half-life.
**- indicates treatment was not observed, based on slope of first order regression line.

TABLE 34. DEGRADATION KINETIC INFORMATION FOR PAH COMPOUNDS IN PENTACHLOROPHENOL WOOD PRESERVING WASTE REAPPLIED TO KIDMAN SANDY LOAM AT -1/3 BAR SOIL MOISTURE, EXPERIMENT H/NR*

				95% Confidence Interval			
				Lower Limit		Upper Limit	
	C_0+ (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)	k (day^{-1})	$t_{1/2}$ (days)
Naphthalene	#						
Fluorene	100	-0.0211	33	-0.0554	13	0.0131	-**
Phenanthrene	950	-0.0064	109	-0.0200	35	0.0075	-
Anthracene							
Fluoranthene							
Pyrene	510	-0.0001	5000	-0.0589	12	0.0586	-
Benzo(a)anthracene							
Chrysene							
Benzo(b)fluoranthene							
Benzo(k)fluoranthene							
Benzo(a)pyrene							
Benzo(ghi)perylene							
Dibenz(a,h)anthracene							
Indeno(1,2,3-cd)pyrene	0.4	-0.0030	231	-0.0161	43	0.0100	-

*H/NR = originally loaded at high rate (0.3%), not reloaded.

+C_0 = initial soil concentration immediately after waste incorporation into soil.

#No data indicate insufficient quantitative information to calculate half-life.

**- indicates treatment was not observed, based on slope of first order regression line.

TABLE 35. DEGRADATION KINETIC INFORMATION FOR PENTACHLOROPHENOL IN PENTACHLOROPHENOL WOOD PRESERVING WASTE REAPPLIED TO DURANT CLAY LOAM SOIL AT -1 BAR SOIL MOISTURE

Loading Rate	C_o* (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)	p$^+$
M/M#	4.0E2	0.0016	433	+
H/NR**	2.3E2	0.0027	257	+

*C_o = initial soil concentration immediately after waste incorporation into soil.

$^+$+ $p > 0.15$ (<85%).

#M/M = originally loaded at medium rate (0.5%), reloaded at medium rate.

**H/NR = originally loaded at high rate (0.7%), not reloaded.

TABLE 36. DEGRADATION KINETIC INFORMATION FOR PENTACHLOROPHENOL IN PENTACHLOROPHENOL WOOD PRESERVING WASTE REAPPLIED TO KIDMAN SANDY LOAM SOIL AT -1/3 BAR SOIL MOISTURE

Loading Rate	C_o* (mg/kg)	k (day^{-1})	$t_{1/2}$ (days)	p$^+$
M/M#	2.7E2	0.0024	289	0.15
L/H**	1.6E2	0.0046	151	0.05
N/H++	-##	0.0021	330	0.05
H/NR***	1.8E2	0.0034	204	0.10

*C_o = initial soil concentration immediately after waste incorporation into soil.

$^+p \underline{<} 0.01$ (99%).
$p \overline{<} 0.05$ (95%).
$p \overline{<} 0.10$ (90%).
$p \overline{<} 0.15$ (85%).

#M/$\overline{M}$ = originally loaded at medium rate (0.15%), reloaded at medium rate.

**L/H = originally loaded at low rate (0.075%), reloaded at high rate (0.3%).

++N/H = nonacclimated soil loaded at high rate (0.3%).

##- = not analyzed.

***H/NR = originally loaded at high rate (0.3%), not reloaded.

wastes were reapplied to soils. PAH degradation generally did not appear to be influenced by soil type. PAH degradation in petroleum refinery wastes exhibited faster kinetics than for wood preserving wastes. Degradation rates for some PAH compounds in complex matrices, such as hazardous wastes, appeared to degrade faster than when present in soil systems as individual compounds.

Half-life values for some PAH constituents in the four complex wastes appeared to be independent of waste loading rate within the range of loading rates evaluated. These results would be expected if degradation followed a first order kinetic model for the range of loading rates for each hazardous waste evaluated.

High molecular weight PAH compounds have been demonstrated to be cometabilized (Sims and Overcash 1983). It is possible that the four complex wastes evaluated in this study, at loading rates that were below a toxic level to soil microorganisms, provided substrates for cell growth and energy production which resulted in the degradation of high molecular weight PAH compounds through a cometabolic process.

Results for pentachlorophenol degradation kinetics in PCP waste indicated a decrease in half-life with increase in incubation time, and when soil initially loaded at the lowest loading rate received a reapplication of waste at the highest loading rate. Acclimation of soil microorganisms to PCP could result in the increase in degradation kinetics observed.

SECTION 5

WASTE TRANSFORMATION EVALUATION

INTRODUCTION

Federal land treatment regulations identified previously (40 CFR Part 262.272) include transformation of hazardous constituents as an acceptable treatment mechanism for land-applied wastes. Transformation of waste constituents for the four wastes investigated was evaluated through chemical and bioassay techniques. Transformation was evaluated by determining the change in toxicity of the waste/soil extract over time of incubation in soil as parent compounds are degraded and intermediates are formed. The Microtox toxicity assay was used to measure and compare the relative acute toxicity of the water soluble fraction (WSF) for each soil/waste mixture through treatment time.

In addition, since many of the parent compounds identified in all four wastes have been identified as mutagens and several compounds have been identified as carcinogens, the Ames mutagenicity assay also was used to evaluate the extent of transformation of the waste. The Ames assay was used to evaluate the soil/waste mixture at the initiation and at the termination of the study for each waste and for the two soils used. Using this assay, the reductions in the mutagenicity of the waste/soil mixtures were determined as a function of treatment (incubation) time.

MATERIALS AND METHODS

The bioassays used included the Microtox toxicity assay and the Ames Salmonella mutagenicity assay. These assays were conducted as described in Volume 1 of this report with one modification to the Ames procedure. One mutagenicity test was performed per extract of each soil/waste mixture with triplicate plates used for each dose. Evaluations of acute toxicity and potential mutagenicity are based on the information given previously concerning that interpretation.

RESULTS AND DISCUSSION

Acute toxicity results of the WSF of each waste incubated in the Durant clay loam soil are presented in Figures 2 through 5 for low moisture soil, and in Figures 6 through 9 for high moisture soil. For the first experimental period of approximately 200 days, the WSF toxicity of API separator sludge increased with initial waste loading rate, as well as with incubation time.

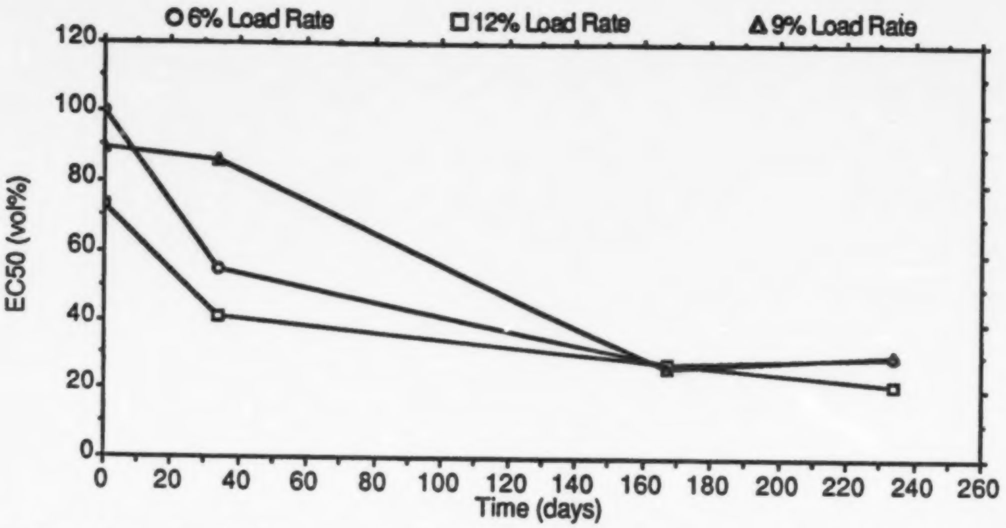

Figure 2. Toxicity of water soluble fraction measured by the Microtox assay with incubation time at low moisture content for API separator sludge mixed with Durant clay loam soil. (EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.)

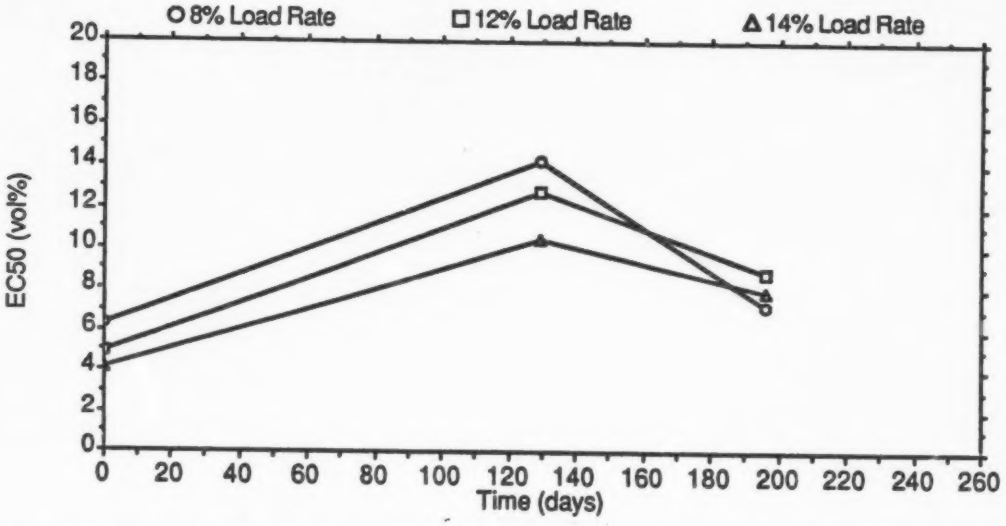

Figure 3. Toxicity of water soluble fraction measured by the Microtox assay with incubation time at low moisture content for slop oil waste mixed with Durant clay loam soil. (EC50 (5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.)

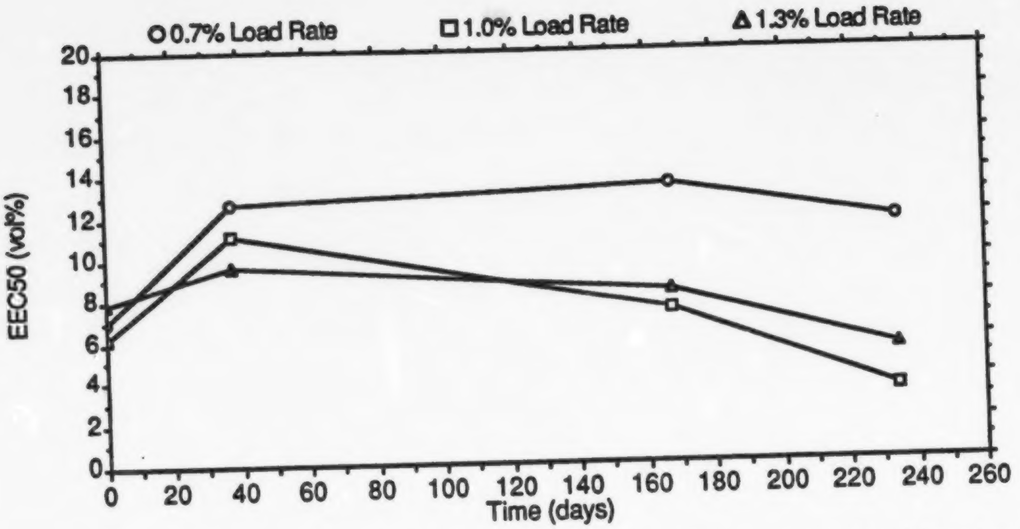

Figure 4. Toxicity of water soluble fraction measured by the Microtox assay with incubation time at low soil moisture content for creosote waste mixed with Durant clay loam soil. (EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.)

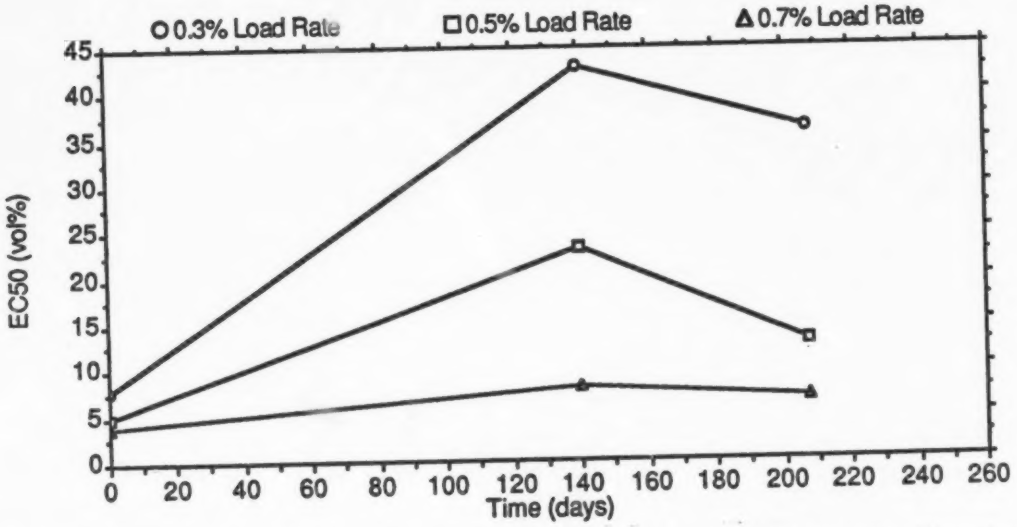

Figure 5. Toxicity of water soluble fraction measured by the Microtox assay with incubation time at low soil moisture content for PCP waste mixed with Durant clay loam soil. (EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.)

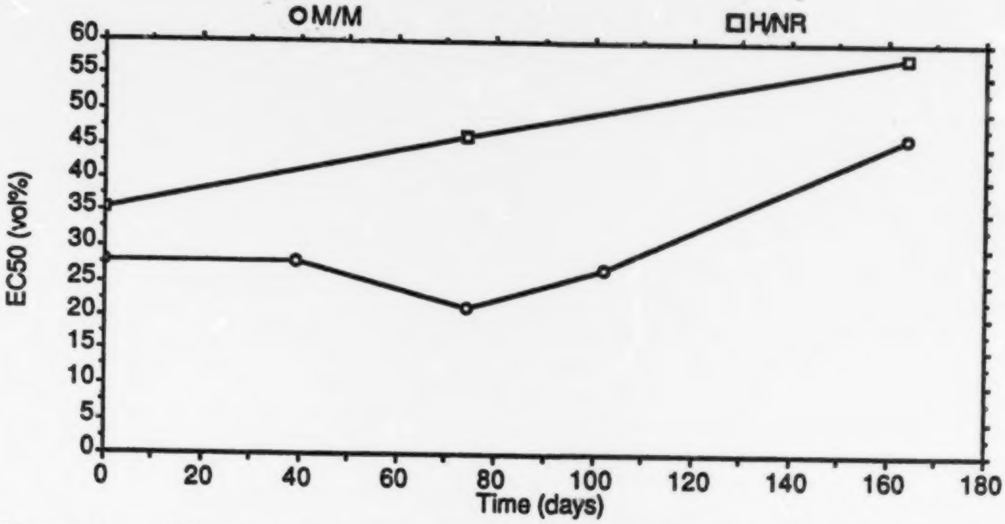

Figure 6. Microtox results with incubation time for API separator sludge waste reapplied to Durant clay loam soil at -1 bar soil moisture. (EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.)

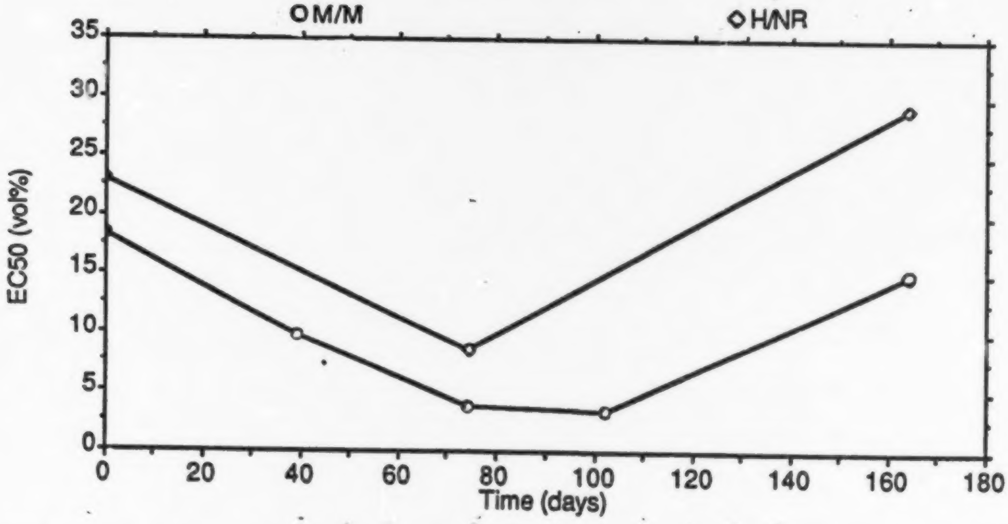

Figure 7. Microtox results with incubation time for slop oil waste reapplied to Durant clay loam soil at -1 bar soil moisture. (EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.)

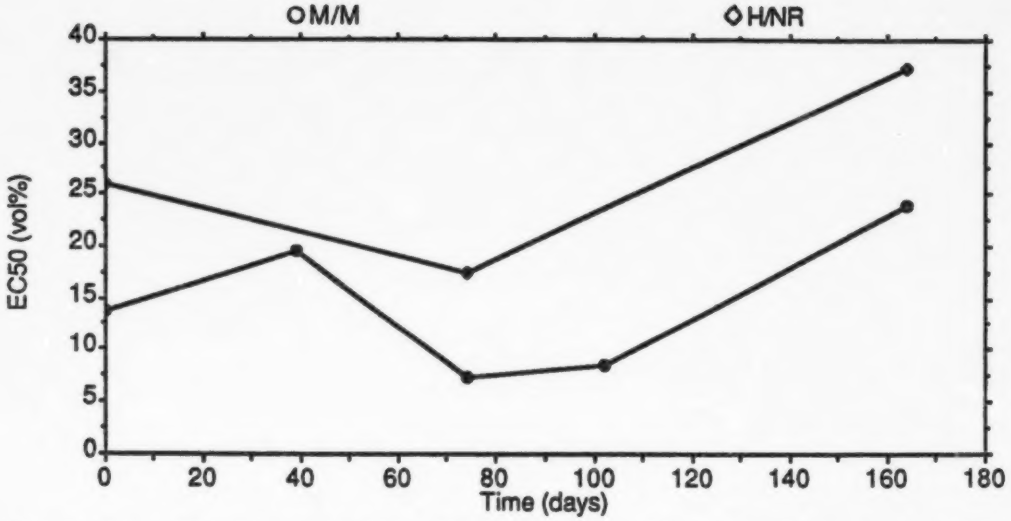

Figure 8. Microtox results with incubation time for creosote waste reapplied to Durant clay loam soil at -1 bar soil moisture. (EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.)

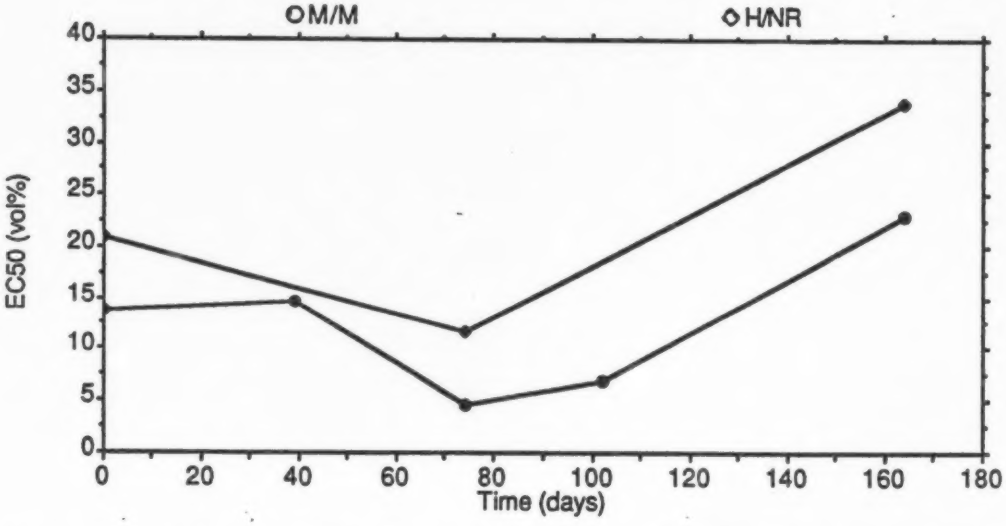

Figure 9. Microtox results with incubation time for PCP waste reapplied to Durant clay loam soil at -1 bar soil moisture. (EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.)

The three waste loading rates used appeared to reach the same level of toxicity (EC50 approximately 30 percent) by day 167.

For API waste in Durant soil at the high loading rate (12 percent waste wet-weight to soil dry-weight), a decrease in toxicity was observed 70 days after initiating the second 200-day experiment (Figure 6). For the medium load soil, reapplication of the medium loading resulted in gradual decrease in toxicity (Figure 6).

For the slop oil emulsion solids waste in Durant soil, WSF toxicity was apparent through both study periods (Figures 3 and 7). Transformation of the waste is evident at day 129 (Figure 3), however, complete detoxification of the waste was not achieved.

Wood preserving wastes incubated in Durant clay loam soil demonstrated higher toxicity in the WSF extract than with the petroleum wastes. Creosote waste in Durant clay loam soil exhibited initial toxicity of the WSF, and a decrease in toxicity during the second period of incubation (Figure 8). PCP waste demonstrated a decrease in WSF toxicity at the lowest loading rate during the first experimental period (Figure 5), and for the high loading rate during the second experimental period (Figure 9). Reloading PCP at the medium rate resulted in an increase in the WSF toxicity. A pattern of increasing toxicity followed by decreasing toxicity of the WSF extract is apparent during the second experimental period (Figures 8 and 9).

Acute toxicity results for the WSF for the four wastes incubated in Kidman sandy loam soil are presented in Figures 10 through 13 for low moisture soil and Figures 14 through 17 for high moisture soil. All four wastes exhibited trends in WSF toxicities similar to those observed for the Durant clay loam soil during the first experimental period. However, all WSFs are more toxic than observed with the Durant soil. Results for the control soils, i.e., Durant soil and Kidman soil with no waste addition are given in the Appendix. The control soils without waste addition did not exhibit any Microtox toxicity either initially or with time of incubation.

AMES ASSAY

Mutagenic potential was determined for each soil without waste addition (controls), and for soil/waste mixtures for all four wastes immediately after waste incorporation into soil and after approximately one year (400 days) of incubation. The highest loading rate for each soil/waste combination was evaluated. Results are presented in Figures 18 through 33.

Results for the Durant clay loam soil and the Kidman sandy loam soil without waste addition do not exhibit any positive mutagenic response. Figures indicating the lack of mutagenic response for the control soils are presented in the Appendix. The mutagenic ratio of approximately one for both soils indicates that the number of bacterial colonies growing in the presence of the soil extract was approximately the same as the number growing without any soil extract addition. Therefore, the experimental soils do not exhibit any mutagenicity over the range of soil weight evaluated.

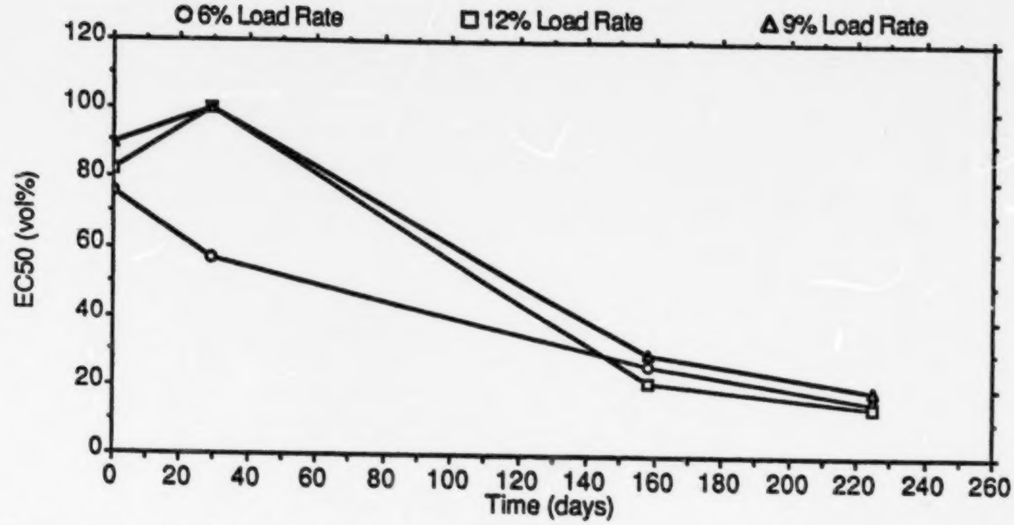

Figure 10. Toxicity of water soluble fraction measured by the Microtox assay with incubation time at low moisture content for API separator sludge mixed with Kidman sandy loam soil. (EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.)

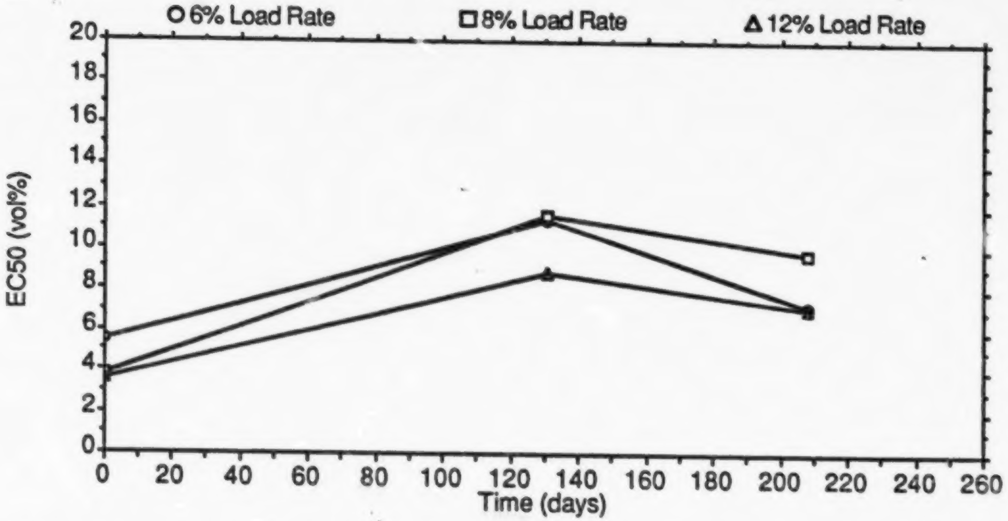

Figure 11. Toxicity of water soluble fraction measured by the Microtox assay with incubation time at low moisture content for slop oil waste mixed with Kidman sandy loam soil. (EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.)

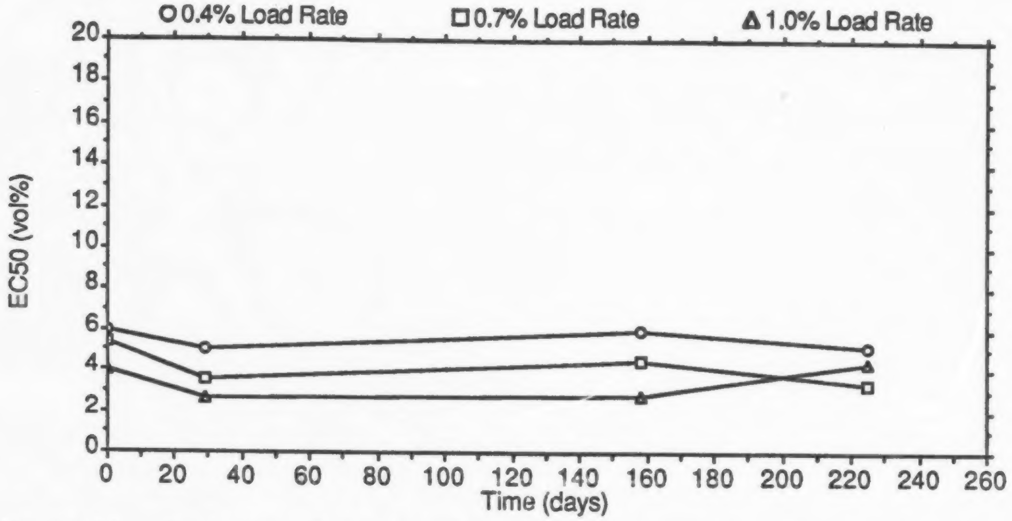

Figure 12. Toxicity of water soluble fraction measured by the Microtox assay with incubation time at low soil moisture content for creosote waste mixed with Kidman sandy loam soil. (EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.)

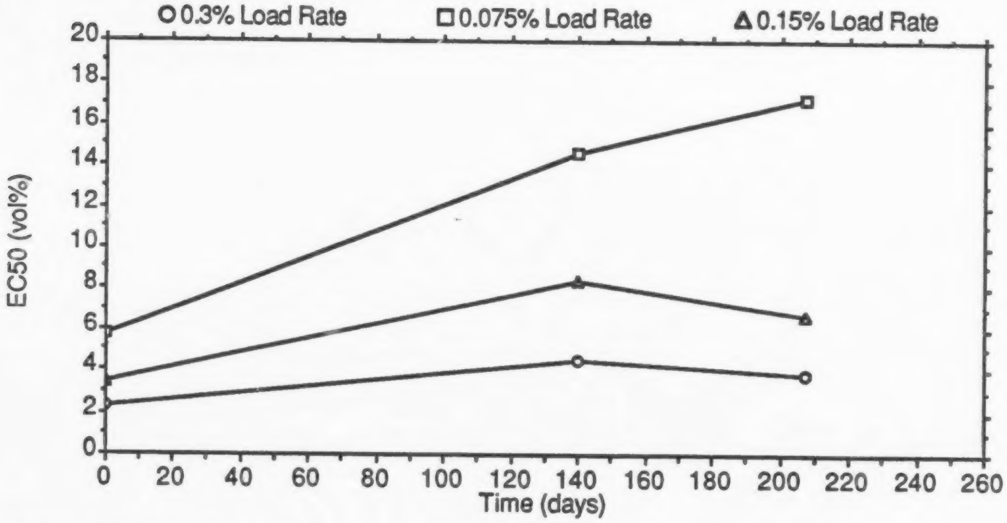

Figure 13. Toxicity of water soluble fraction measured by the Microtox assay with incubation time at low soil moisture content for PCP waste mixed with Kidman sandy loam soil. (EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.)

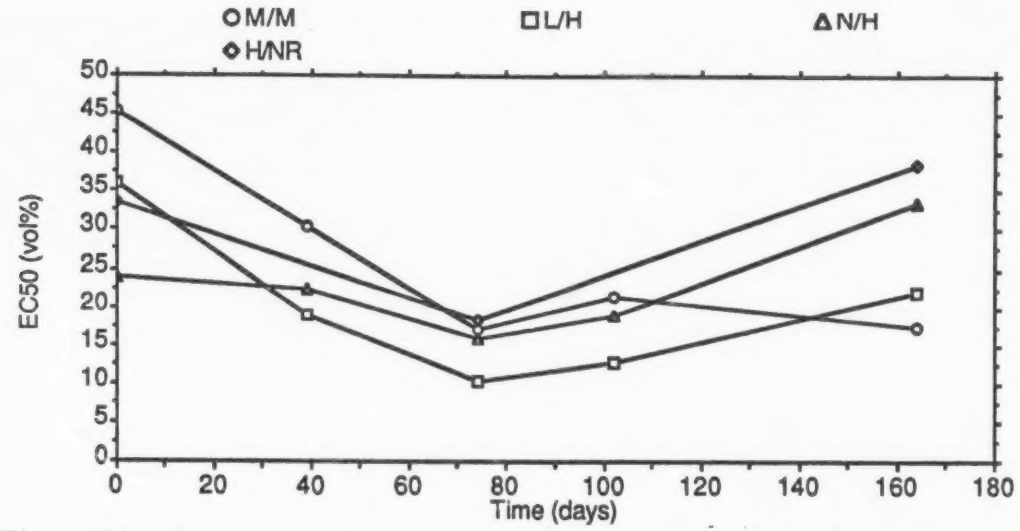

Figure 14. Microtox results with incubation time for API separator sludge waste reapplied to Kidman sandy loam soil at -1/3 bar soil moisture. (EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.)

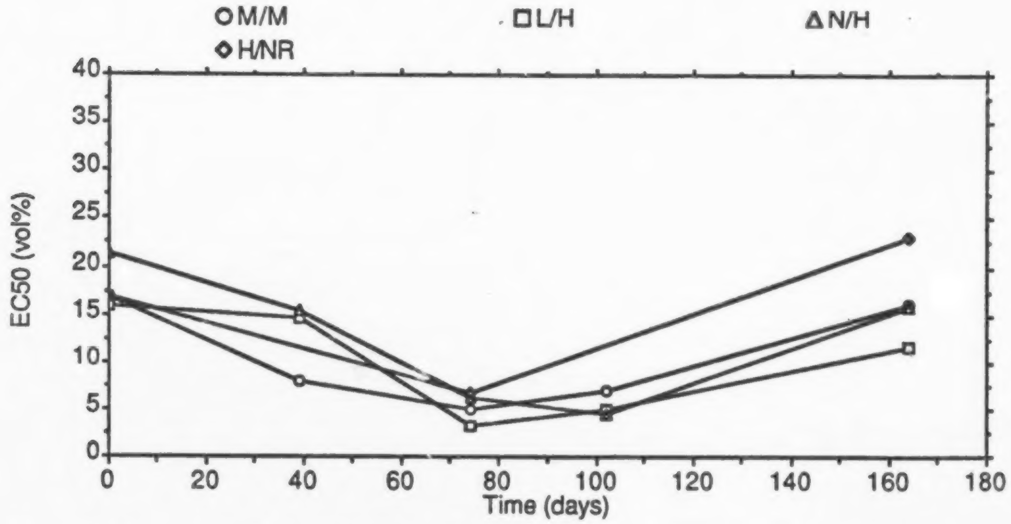

Figure 15. Microtox results with incubation time for slop oil waste reapplied to Kidman sandy loam soil at -1/3 bar soil moisture. (EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.)

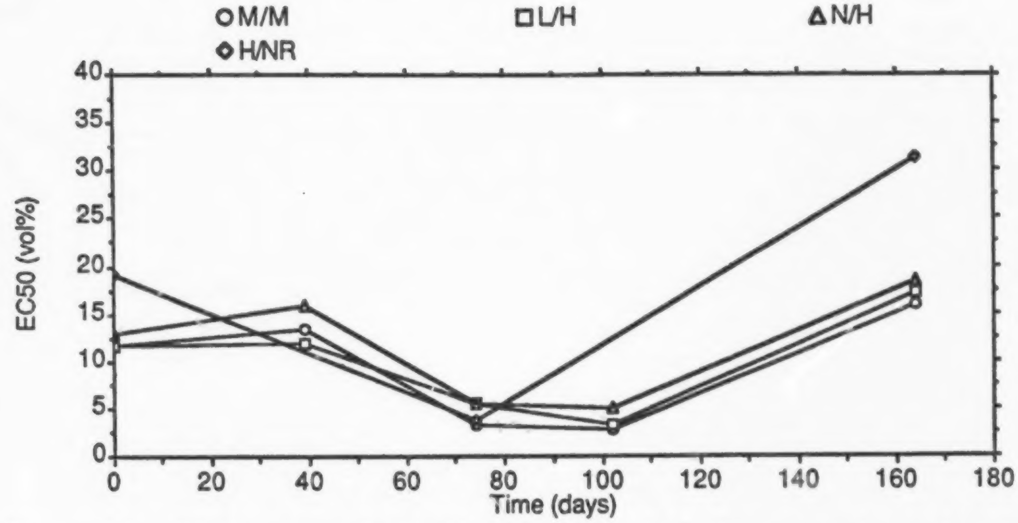

Figure 16. Microtox results with incubation time for creosote waste reapplied to Kidman sandy loam soil at -1/3 bar soil moisture. (EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.)

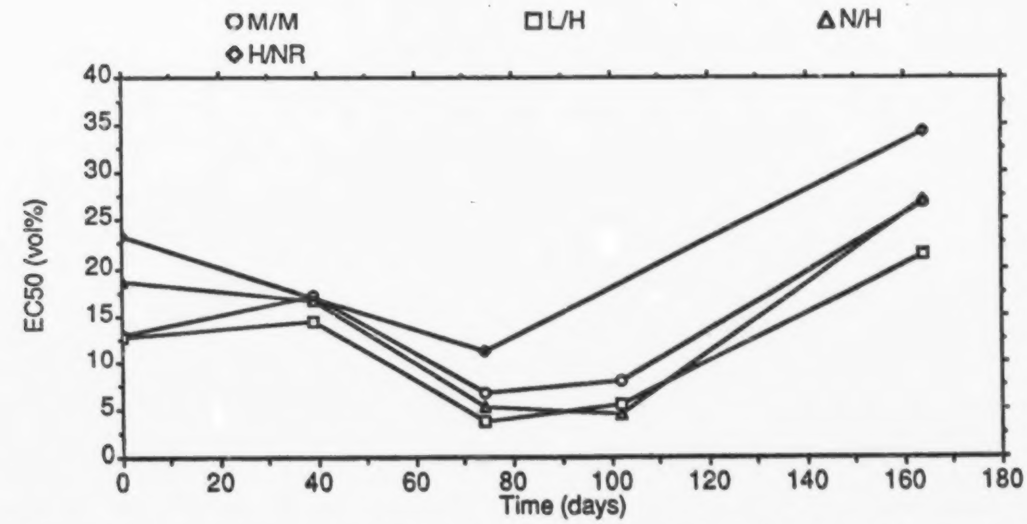

Figure 17. Microtox results with incubation time for PCP waste reapplied to Kidman sandy loam soil at -1/3 bar soil moisture. (EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.)

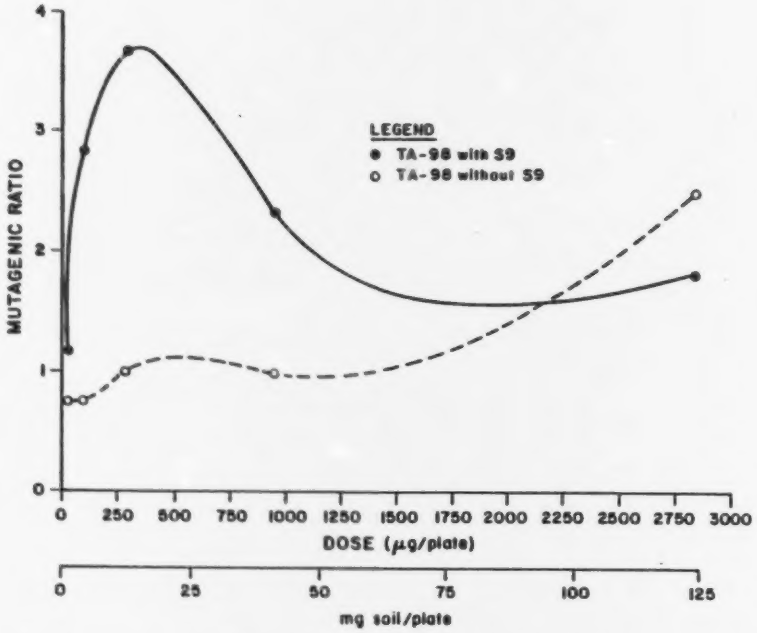

Figure 18. Ames assay results for 12% API separator sludge in Durant clay loam soil immediately after waste incorporation into soil.

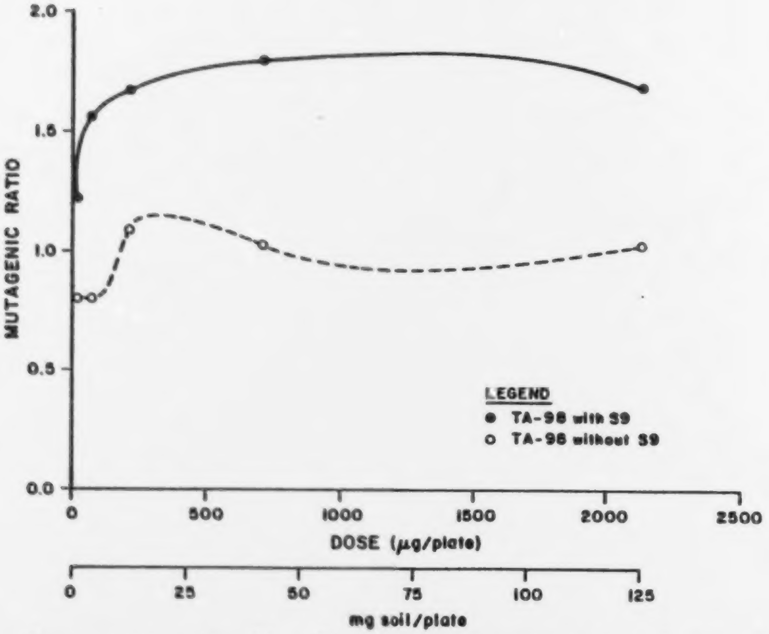

Figure 19. Ames assay results for 12% API separator sludge in Durant clay loam soil after 400 days incubation.

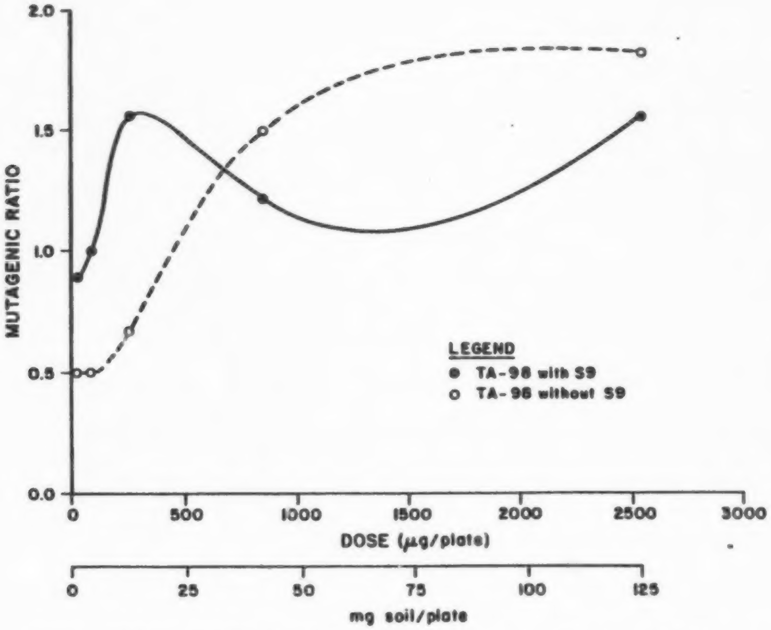

Figure 20. Ames assay results for 12% API separator sludge in Kidman sandy loam soil immediately after waste incorporation into soil.

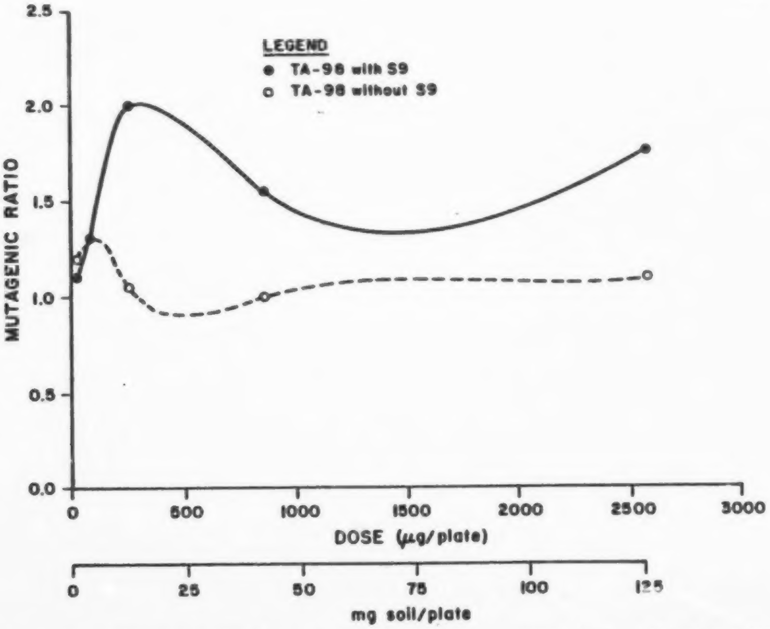

Figure 21. Ames assay results for 12% API separator sludge in Kidman sandy loam soil after 400 days incubation.

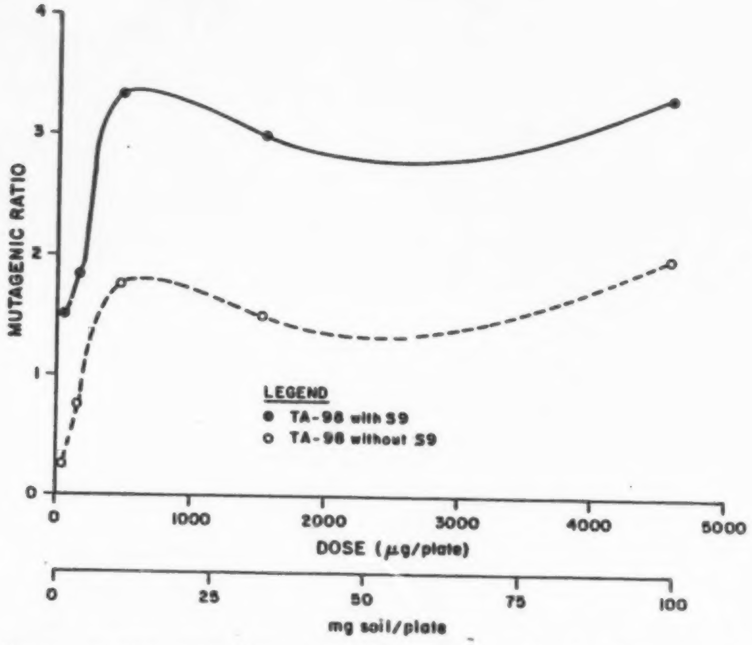

Figure 22. Ames assay results for 14% slop oil in Durant clay loam soil immediately after waste incorporation in soil.

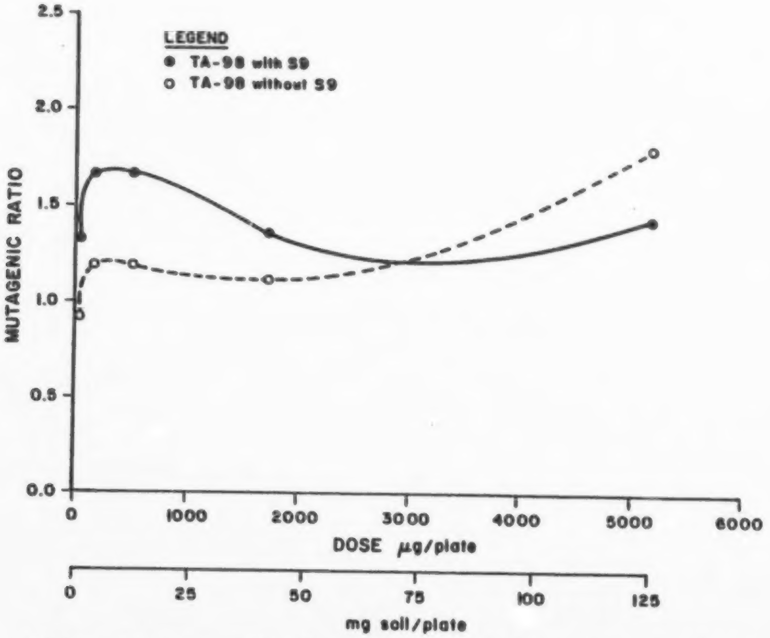

Figure 23. Ames assay results for 14% slop oil in Durant clay loam soil after 400 days incubation.

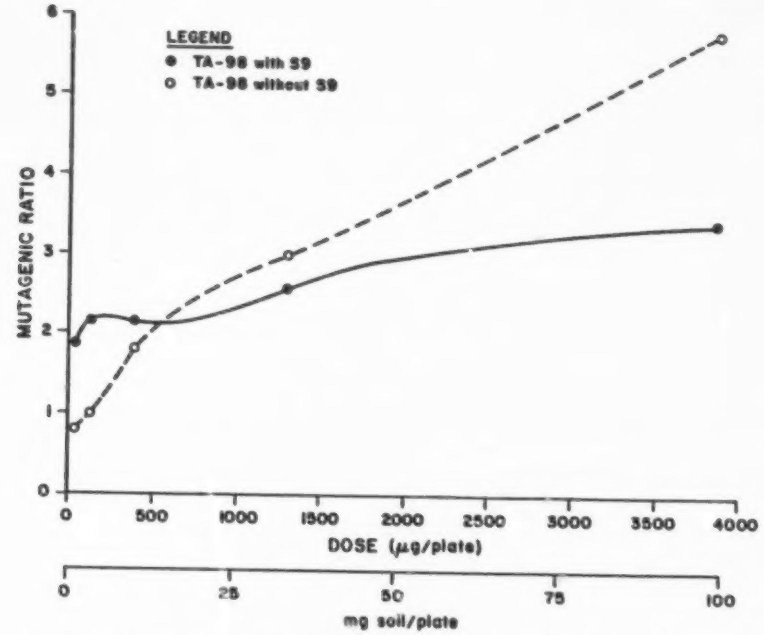

Figure 24. Ames assay results for 12% slop oil in Kidman sandy loam soil immediately after waste incorporation into soil.

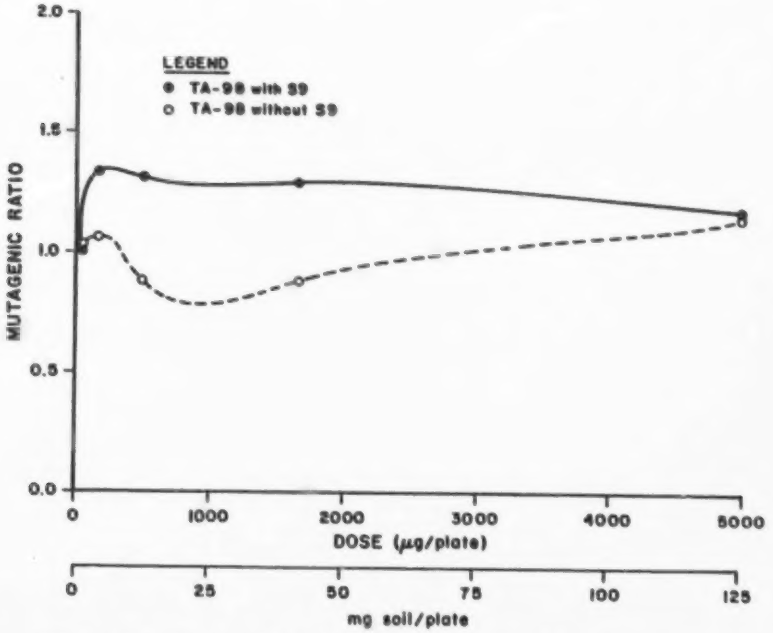

Figure 25. Ames assay results for 12% slop oil in Kidman sandy loam soil after 400 days incubation.

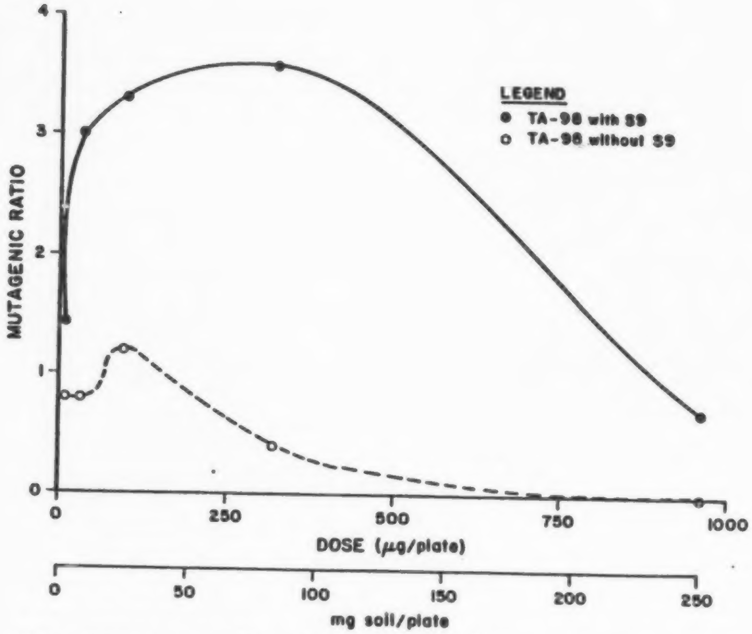

Figure 26. Ames assay results for 1.3% creosote sludge in Durant clay loam soil immediately after waste incorporation into soil.

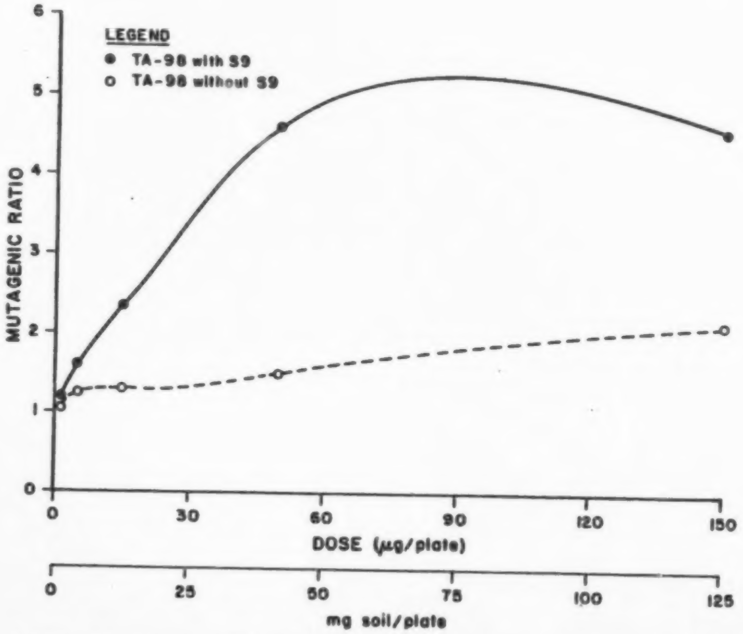

Figure 27. Ames assay results for 1.3% creosote sludge in Durant clay loam soil after 400 days of incubation.

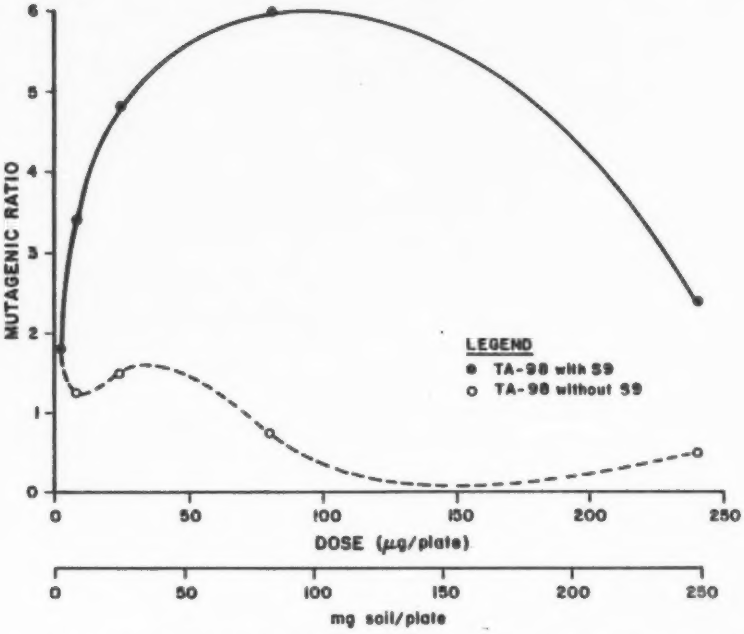

Figure 28. Ames assay results for 1.0% creosote sludge in Kidman sandy loam soil immediately after waste incorporation into soil.

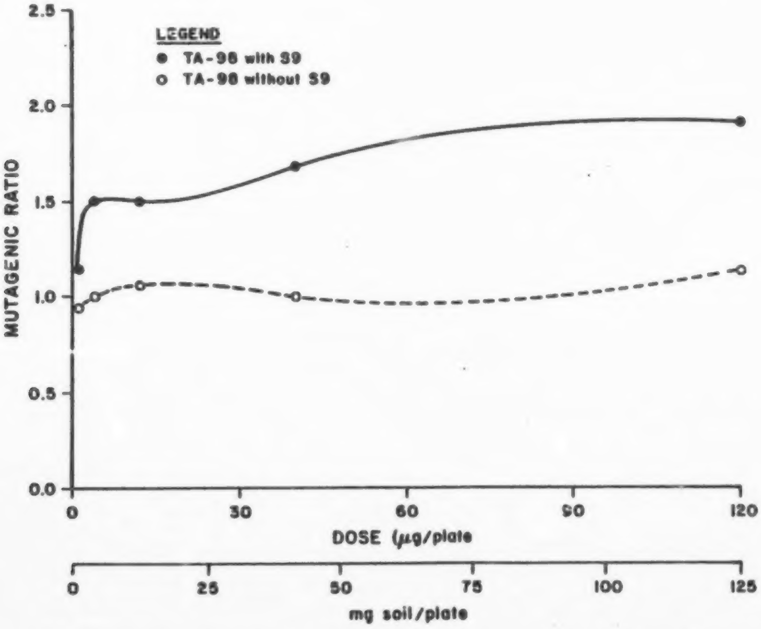

Figure 29. Ames assay results for 1.0% creosote in Kidman sandy loam soil after 400 days of incubation.

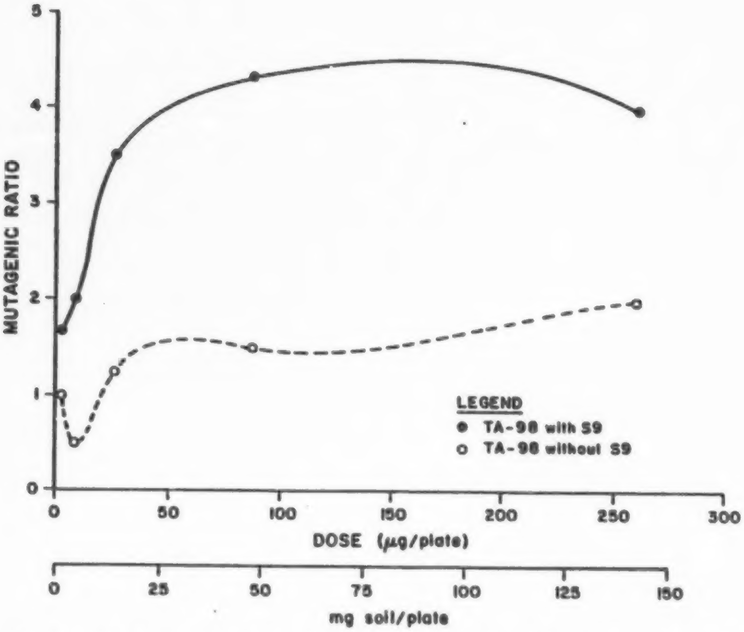

Figure 30. Ames assay results for 0.7% pentachlorophenol sludge in Durant clay loam soil immediately after waste incorporation into soil.

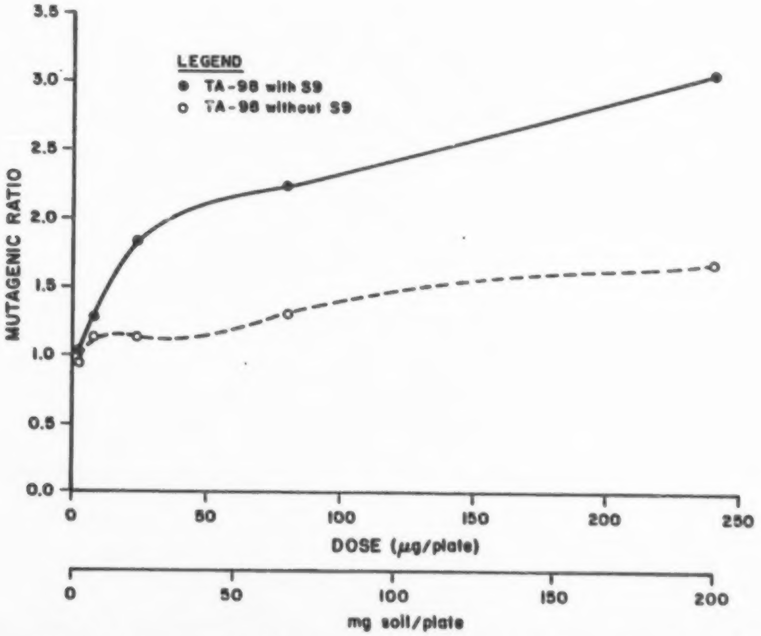

Figure 31. Ames assay results for 0.7% pentachlorophenol sludge in Durant clay loam soil after 400 days incubation.

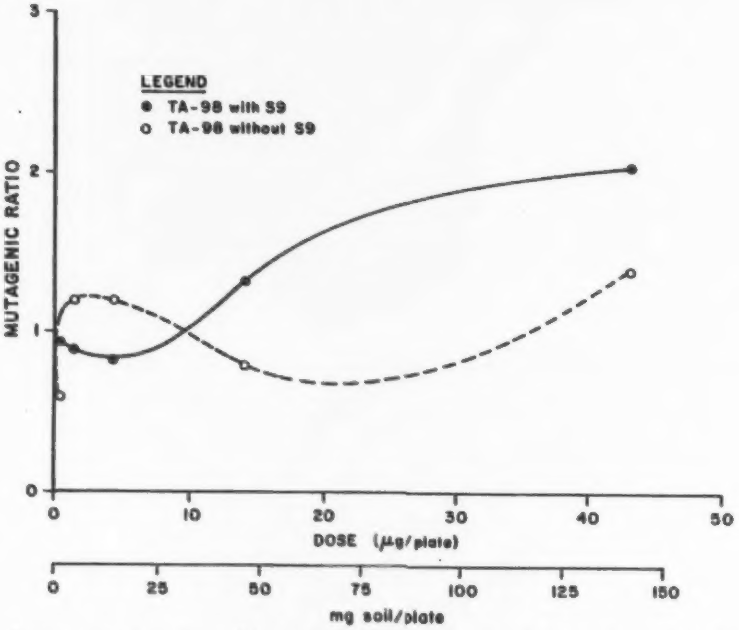

Figure 32. Ames assay results for 0.3% pentachlorophenol sludge in Kidman sandy loam soil immediately after waste incorporation into soil.

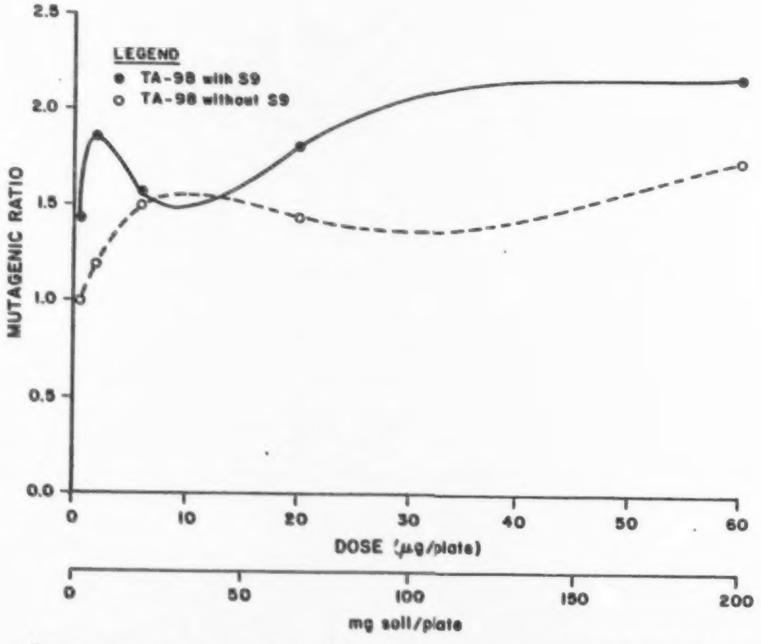

Figure 33. Ames assay results for 0.3% pentachlorophenol sludge in Kidman sandy loam soil after 400 days of incubation.

A postive mutagenic potential (mutagenic ratio greater than 2.5) was observed for both petroleum wastes in Durant clay loam soil immediately after waste incorporation into soil (Figures 18 and 22). With Kidman sandy loam soil only slop oil emulsion solids exhibited an initial mutagenicity (Figure 24). Mutagenic activity was not observed in any petroleum waste/soil extracts after 400 days of treatment (Figures 19, 21, 23, and 25), indicating a detoxification pathway in the soils for these wastes.

For the wood preserving wastes, positive mutagenic potential was observed for both wastes in Durant clay loam soil immediately after waste incorporation into soil (Figures 26 and 30). With Kidman sandy loam soil only creosote waste exhibited an initial mutagenicity (Figure 28). A positive mutagenic potential was observed after 400 days of treatment for both wood preserving wastes incubated in Durant clay loam soil at the highest loading rates (Figures 27 and 31). No positive mutagenic potential was detected in PCP waste incubated in Kidman sandy loam soil at 0.3 percent loading (Figures 32 and 33). For the creosote waste in Kidman sandy loam soil, mutagenic activity was not evident after 400 days of treatment (Figure 29), indicating detoxification of creosote waste in Kidman sandy loam soil.

It is difficult to compare Durant clay loam soil to Kidman sandy loam soil with respect to mutagenicity reduction efficiency since the loading rates were different for the two soils for three of the four wastes studied for mutagenicity.

SUMMARY

Microtox assay results indicated that transformation of hazardous organic constituents occurred in all waste soil combinations evaluated. An increase in WSF toxicity was observed for all waste/soil mixtures evaluated during the first experimental period, and a decrease in WSF toxicity was generally observed during the second experimental period.

Results obtained from transformation evaluations using the Microtox assay agree with observations from the bioassay comparative study reported in the Loading Rate Evaluation Section, Volume 1. The Microtox assay again proved to be an extremely sensitive assay which may not correlate with gross degradation indicators such as respiration studies, and therefore should not be used to positively identify an actual loading rate at which soil biodegradation will be inhibited. Loading rates actually used in the study were generally higher than those suggested as a result of using the Microtox assay in the initial loading rate studies. The rationale for selection of higher loading rates was the confirmation that biodegradation occurred, as evidenced by carbon dioxide evolution and by other metabolic activity studies, at higher loading rates. However, since WSF toxicity results indicated that transformation of the waste occurred for all waste/soil combinations, and that the WSF may contain hazardous intermediate products, it may be concluded that lower loading rates, i.e., rates closer to the ones initially indicated based on Microtox assay, results should be used in future studies if the treatment criterion desired is complete detoxification of the waste-soil mixture.

Results from mutagenicity evaluations for soil detoxification of petroleum refinery wastes indicated a reduction from mutagenic to nonmutagenic activity with treatment time for API separator sludge in Durant clay loam soil and for slop oil emulsion solids incubated in Durant clay loam and in Kidman sandy loam soils. Wood preserving wastes, however, were not rendered nonmutagenic after 400 days of soil incubation in Durant clay loam soil at waste loading rates of 1.3 percent and 0.7 percent for creosote and PCP wastes, respectively. However, no mutagenicity was detected at a loading rate of 0.3 percent PCP waste in Kidman sandy loam soil, and the initial positive mutagenic potential for a loading rate of 1.0 percent creosote waste was reduced to a nonmutagenic level with a treatment time of 400 days.

These results indicate the importance of waste loading and site selection and management for land treatment units receiving hazardous wastes. Treatability studies can provide valuable information concerning selection of loading rates and the production of intermediate products in soil-waste mixtures that may require careful site management.

SECTION 6

WASTE IMMOBILIZATION EVALUATION

INTRODUCTION

Mobility includes the downward transport, or leaching potential, and upward transport, or volatilization potential of waste constituents. Transport is evaluated in order to ensure that treatment (degradation, transformation, or immobilization) will occur in the treatment zone. The transport potential for waste constituents to migrate or partition from the waste to water, air, and/or soil phases will be affected by the relative affinity of the waste constituents for each phase. Approaches to the evaluation of the mobility of a waste in this study included laboratory column studies and laboratory partition studies to determine partition coefficients.

Laboratory column studies were conducted in order to evaluate the integrated toxicity of leachate produced in short (50 cm) column studies containing the experimental soils and wastes. The purpose for using short columns was to evaluate the "potential" for separation and transport of toxicity in the WSF (leachate), not for predicting or evaluating the likelihood of generating toxic leachates from the downward transport of water through the 5 ft waste treatment zone. The water loading for all columns exceeded the 100 year flood event by a factor of 4 for anywhere in the United States.

Studies were also conducted to develop and evaluate preliminary techniques and approaches to determining partition coefficient. The relative affinity or distribution of waste constituents among the four environmental phases identified previously, i.e., waste, water, air, and soil, may be quantified by determining distribution or partition coefficients. Partition coefficients are defined and evaluated as follows:

$$K_o = \frac{\text{constituent(s) concentration in waste or oil phase}}{\text{constituent(s) concentration in aqueous phase}}$$

$$K_d = \frac{\text{constituent(s) concentration in the soil phase}}{\text{constituent(s) concentration in aqueous phase}}$$

$$K_h = \frac{\text{constituent(s) concentration in the air phase}}{\text{constituent(s) concentration in aqueous phase}}$$

$$K_{ao} = \frac{\text{constituent(s) concentration in the air phase}}{\text{constituent(s) concentration in aqueous phase}}$$

Constituent-specific partition coefficients can be used as input parameters for the proposed treatment zone model for soil processes (Appendix B), along with degradation data, for evaluating the fate and transport of hazardous constituents in soil systems.

MATERIALS AND METHODS

Column Studies

Column studies were performed to evaluate immobilization potential of waste based on the Microtox^{TM} toxicity of leachate samples. Duplicate laboratory columns were prepared for each waste-soil combination (4 wastes x 2 soils x 2 replicates = 16 columns), and immobilization was evaluated under saturated soil conditions immediately after waste incorporation into soil (initial study). Waste-soil mixtures which had been incubated for 1 year under high soil moisture conditions (-1/3 to -1 bar) were also applied to another set of columns (4 wastes x 2 soils x 1 replicate = 8 columns). Since degradation studies and Microtox system results had indicated general PAH degradation and transformation after 1 year of soil treatment at high soil moisture, it was considered important to evaluate the immobilization potential of waste where transformation of intermediate degradation products are likely present.

Glass columns (50 cm x 5 cm I.D.) fitted with glass frits and teflon stopcocks were used for the studies. The columns were packed to 35 cm with air-dried Durant clay loam or Kidman sand loam (= 662 g soil for Durant clay loam and 912 g for Kidman sandy loam). For the initial study, wastes were incorporated into the top 8 cm (147 g for Durant soil; 195 g for Kidman soil) at the high rates determined for each soil:waste combination. Initially the columns were gravimetrically back-fed with deionized water in order to replace the air from pore spaces with water. Water was then allowed to percolate through the columns with the leachate collected at the bottom. Water was continuously added to the top of each column, with an 8 cm head maintained by a tube allowing any excess water to drain off. The flow rate for each column was adjusted to allow for collection of one pore volume (determined to be approximately 300 ml for both soils) per day.

In the second study, one column was prepared for each soil:waste combination. Column preparation was identical to that of the initial study except that the amount of the Kidman soil:waste mixtures used was approximately 75 percent (by weight) less than was used in the first study.

Leachate samples, collected as column pore volumes, were analyzed for toxicity using the Microtox toxicity system.

Partition Coefficient Determination

Experimental Procedure--

Partition coefficients among waste, water, and air phases were determined for several major components (PAHs and volatile aromatic hydrocarbons) of each waste. Figure 34 shows the sample preparation and analysis scheme for the

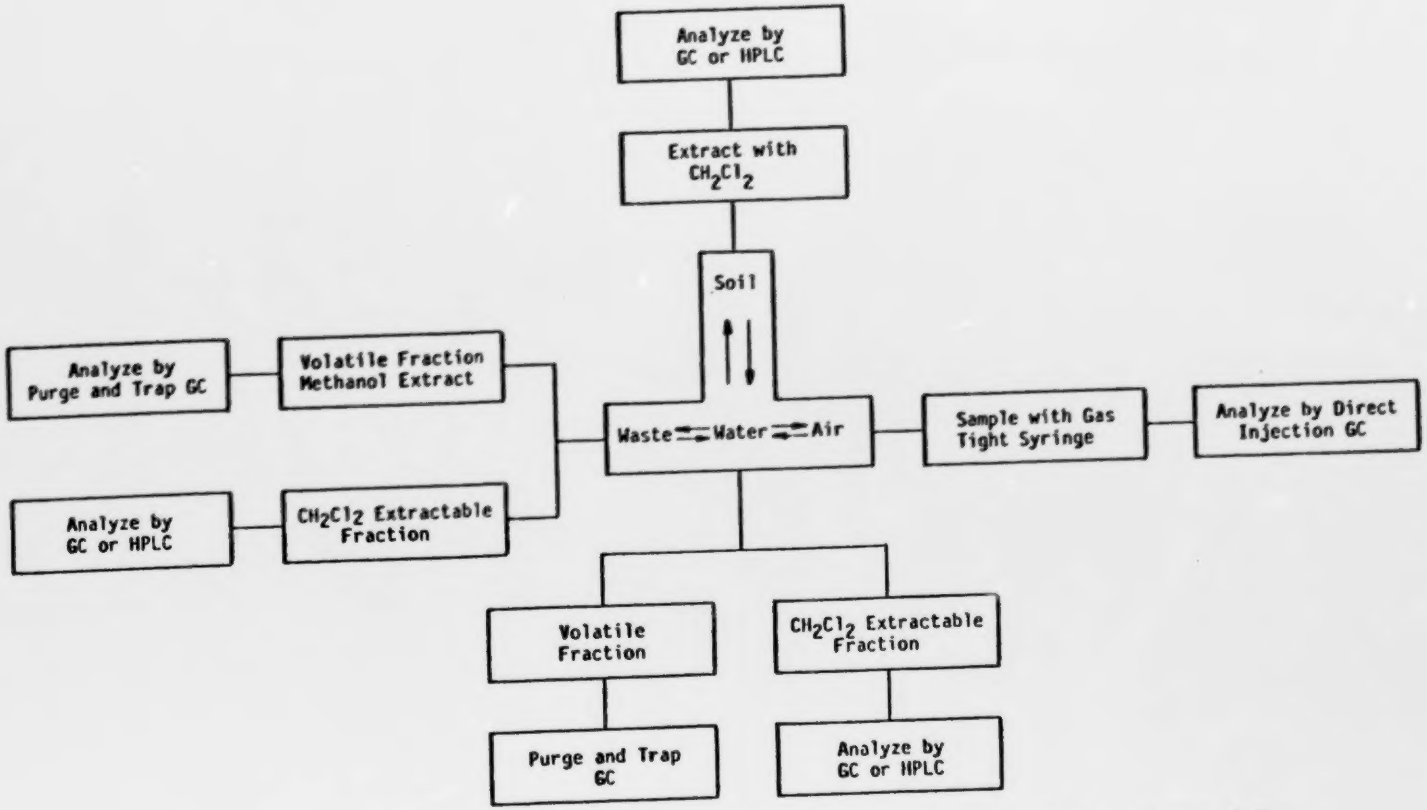
Analyze by GC or HPLC
Extract with CH_2Cl_2
Soil
Analyze by Purge and Trap GC
Volatile Fraction Methanol Extract
Waste ⇌ Water ⇌ Air
Sample with Gas Tight Syringe
Analyze by Direct Injection GC
Analyze by GC or HPLC
CH_2Cl_2 Extractable Fraction
Volatile Fraction
CH_2Cl_2 Extractable Fraction
Purge and Trap GC
Analyze by GC or HPLC

Figure 34. Sample preparation and analysis scheme for the determination of K_H, K_D, and K_o.

determination of the partition coefficients. Due to the low water solubility of the major constituents of concern, it was not possible to determine soil/water partition coefficient (K_D) for the complex wastes.

A partition coefficient was calculated for evaluating the distribution of constituents between the waste (or oil) and air phases (K_{oi}). This partition coefficient may be used to assess the relative affinity of a constituent for the air phase in the presence of a waste (oil) phase. K_{oi} therefore is an indicator of the extent of volatilization from the waste (oil) phase.

Ten grams waste (wet weight) and 75 ml distilled deionized water (DDW) were added to 150 ml glass bottles with sealable top (see Figure 35) the bottles were sealed with an aluminum cap and teflon-lined septa and then placed in a rotary shaker at 30 rpm for 24 hrs. After shaking, the bottles were centrifuged at 2000 rpm for 30 min. Three distinct phases were observed.

The headspace was sampled (1 to 4 ml) with a gas-tight syringe and analyzed by direct injection gas chromatography (GC) with flame ionization detector.

Three aliquots of the aqueous phase were taken immediately after the headspace sample. One aliquot was used to determine the volatile constituents in the aqueous phase using the purge and trap GC method. A second aliquot was extracted with $CHCl_2$ and analyzed by GC or HPLC to determine the nonvolatile extractable constituents. A third aliquot was equilibrated with soil in a separate glass container for the determination of K_D. After equilibrium the soil was extracted with CH_2Cl_2 and the concentration of constituents determined by GC or HPLC analysis.

Two aliquots of the waste sample were also taken. The methanol extract of one aliquot was analyzed by purge and trap GC to determine the concentration of volatile constituents. The second aliquot was extracted with CH_2Cl_2 and the concentration of nonvolatile constituents determined by GC or HPLC.

Partition coefficients between water and soil, air, and waste phases were calculated from the experimentally determined concentrations in each phase.

RESULTS AND DISCUSSION

Results for laboratory column studies for soils without waste addition (control columns) are presented in Table 37. All leachate samples taken were nontoxic using the Microtox assay. Results for laboratory column studies conducted immediately after initial waste incorporation into soil for all four wastes and for the two experimental soils are presented in Figures 36 through 39. Leachate generated, which amounted to 15 column volumes, for columns containing the petroleum refining waste exhibited nontoxic or very low toxicity values immediately after waste incorporation (Figures 36 and 37). This was observed for the Durant clay loam soil and the Kidman sandy loam soil.

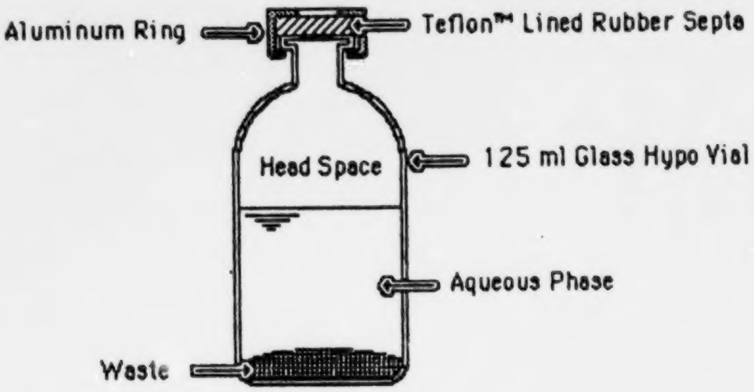
Aluminum Ring
Teflon™ Lined Rubber Septa
Head Space
125 ml Glass Hypo Vial
Aqueous Phase
Waste

Figure 35. Apparatus for partitioning experiments.

TABLE 37. MICROTOX BIOASSAY EVALUATION OF LABORATORY COLUMN LEACHATE FOR CONTROL SOIL

Volume of Leachate (columns volumes)	Durant Clay Loam EC50(5,15^{o})* (vol%)	Kidman Sandy Loam EC50(5,15^{o}) (vol %)
1	NT+	NT
3	NT	NT
5	NT	NT
7	NT	NT
9	NA#	NA
11	NT	NT
13	NT	NT
15	NT	NT

*EC50(5,15^{o}) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15^{o}C.
+NT = no apparent toxic effect.
#NA = no analysis.

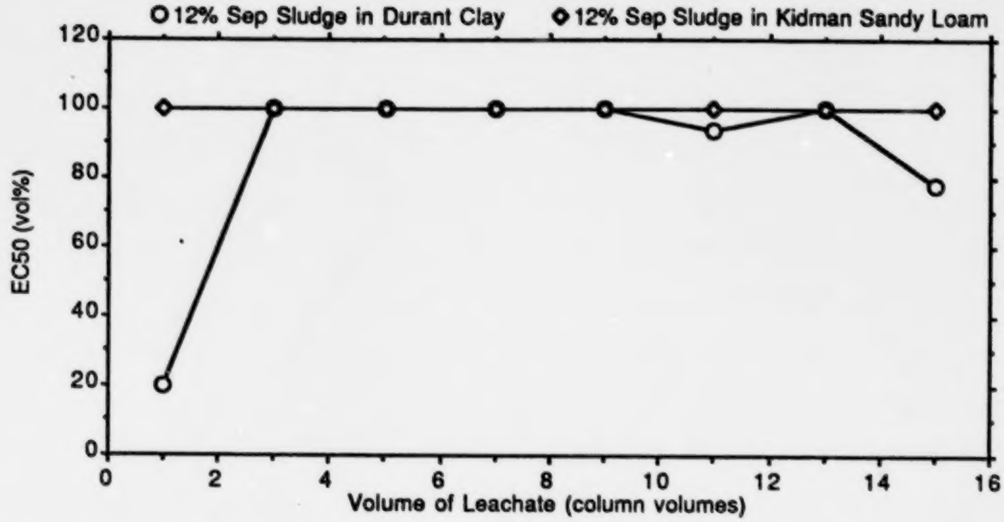

Figure 36. Immobilization of API separator sludge waste as determined by Microtox bioassay evaluation of laboratory column leachate immediately after waste incorporation into soil. (EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.)

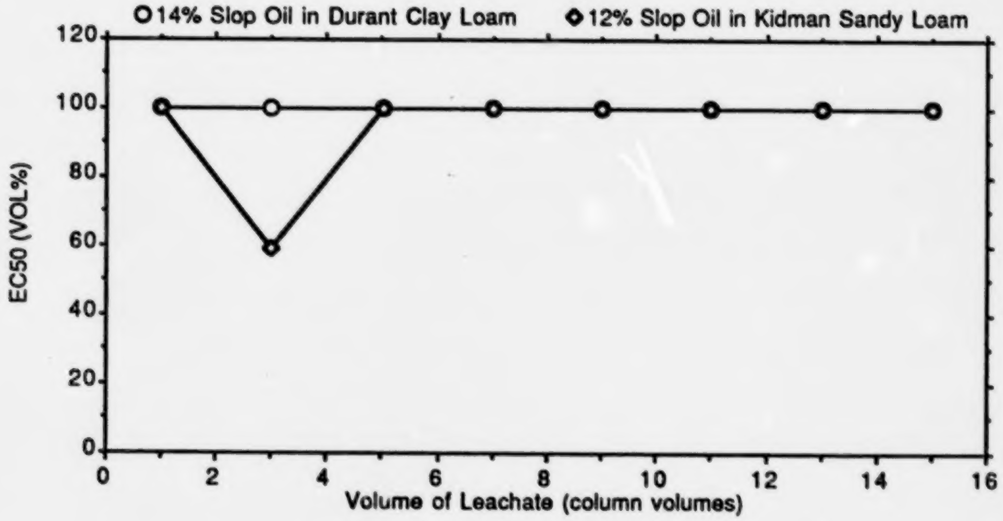

Figure 37. Immobilization of slop oil emulsion solids waste as determined by Microtox bioassay evaluation of laboratory column leachate immediately after waste incorporation into soil. (EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.)

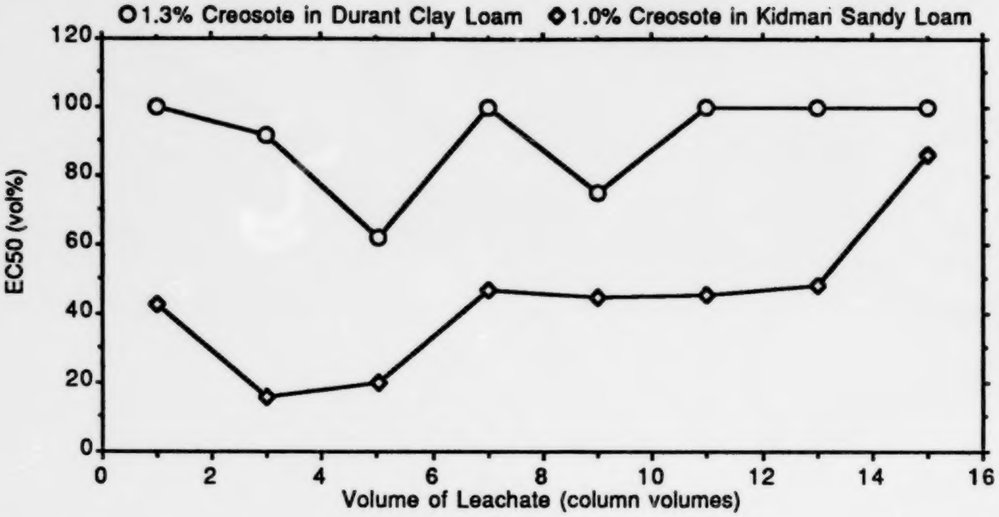

Figure 38. Immobilization of creosote waste as determined by Microtox bioassay evaluation of laboratory column leachate immediately after waste incorporation into soil. (EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.)

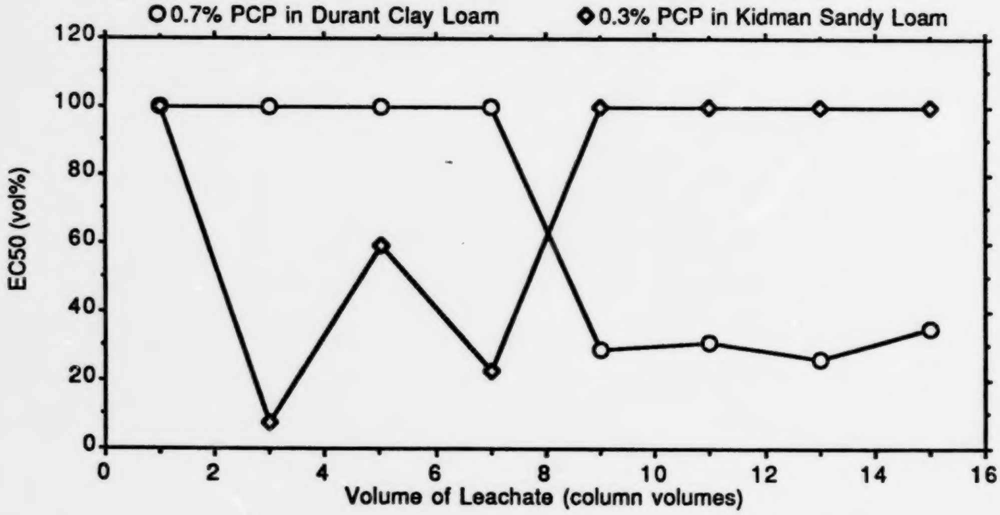

Figure 39. Immobilization of PCP waste as determined by Microtox bioassay evaluation of laboratory column leachate immediately after waste incorporation into soil. (EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.)

Leachate generated in the creosote loaded columns exhibited very low or nontoxic values for the Durant soil (Figure 38). However, leachate from the Kidman soil exhibited a toxic response in every sample analyzed.

Leachate generated in the PCP loaded columns exhibited different responses which appeared to be a function of the soil properties. For the Durant clay loam soil, leachate was not observed to exhibit Microtox toxicity through the first 7 column volumes; however, subsequent leachate had relatively toxic EC50 values for leachate samples from column volumes 9 through 15. For the Kidman sandy loam soil, leachate from the first 7 column volumes exhibited Microtox toxicity; however, subsequent leachate exhibited no toxicity after the 9th column volume. Therefore, the behavior of the columns with respect to Microtox toxicity was opposite and appeared to be related to the soil type. However, it is possible that the different toxicity patterns may have been related to the different PCP loading rates used for the two soil types (Figure 39).

Results for leachates generated from laboratory column studies initiated after approximately one year of treatment for all four wastes and for the two experimental soils are presented in Figures 40 through 43. Leachates from the petroleum waste columns containing Durant clay loam soil were generally less toxic than from columns containing Kidman sandy loam soil (Figures 40 and 41). Leachate from the wood preserving waste columns (Figures 42 and 43) generally exhibited higher Microtox toxicity values than the petroleum wastes even though the loading rates were an order of magnitude smaller. Creosote column leachate generally exhibited lower toxicity than leachate collected from the PCP column. Also, similar to the results obtained immediately after waste incorporation into soil for the PCP waste columns, leachate generated from the column containing Durant soil generally exhibited lower toxicity than leachate generated from the column containing Kidman sandy loam.

Results for partition coefficients for the distribution between waste and water (K_o) for the PAH constituents for the four wastes investigated are presented in Table 38. Values for K_o indicated very high partitioning of PAH constituents into all waste, as expected. K_o values were highest for API separator sludge waste, which were similar to octanol:water (K_{ow}) partition coefficients. Due to the extremely low concentrations of PAH constituents in the aqueous phase, it was not feasible to measure K_D values for these constituents experimentally using the procedure described. Also, only naphthalene could be detected in the air phase in sufficient concentration to determine a partition coefficient between air and water, and their values were included in results for volatile constituents.

Results for partition coefficients for volatile constituents in the four wastes are presented in Tables 39 through 42. Partition coefficients evaluated included K_h (air/water), K_o (oil/water) for the petroleum wastes, K_o (waste/water) for the wood preserving wastes, and K_{ao} (air/waste). The constituents have the greatest affinity for the waste, as indicated by the high values for K_o and K_{ao} compared with K_h. Concentrations of constituents were generally in the ratio of 1:10:10,000 for air:water:oil phases for constituents identified in petroleum waste except for benzene (1:2:5000) and for naphthalene (1:150:100,000). For the wood preserving wastes

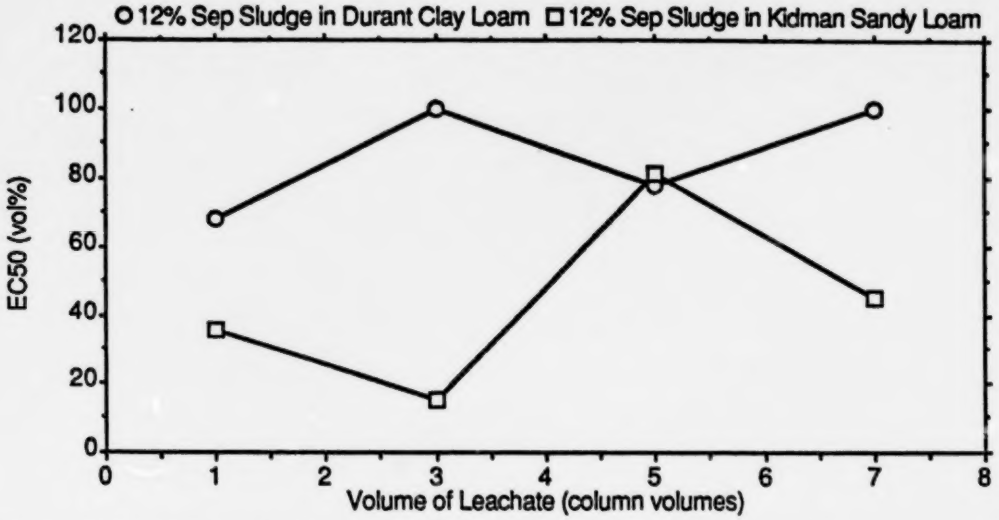

Figure 40. Immobilization of API separator sludge waste as determined by Microtox bioassay evaluation of laboratory column leachate 352 days after waste incorporation into soil. (EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.)

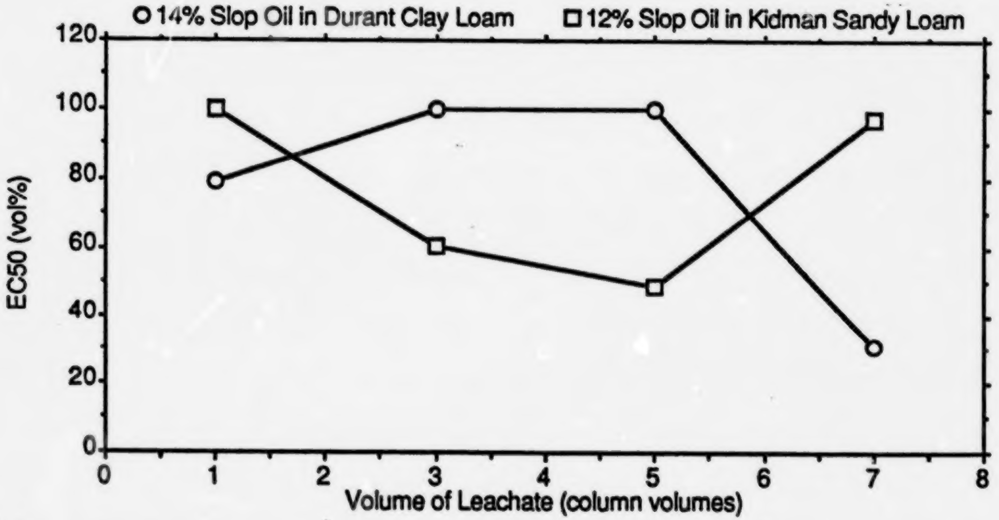

Figure 41. Immobilization of slop oil emulsion solids as determined by Microtox bioassay evaluation of laboratory column leachate 323 days after waste incorporation into soil. (EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.)

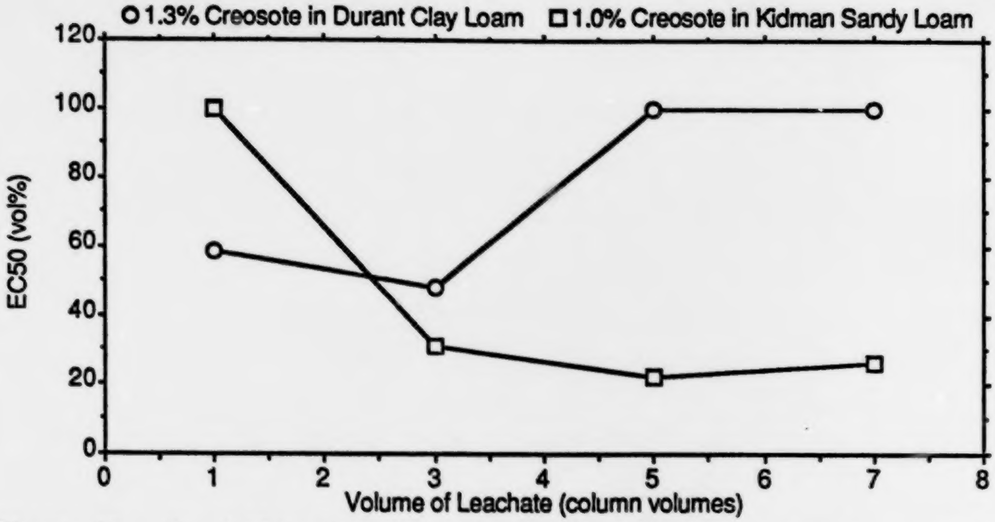

Figure 42. Immobilization of creosote waste as determined by Microtox bioassay evaluation of laboratory column leachate 361 days after waste incorporation into soil. (EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.)

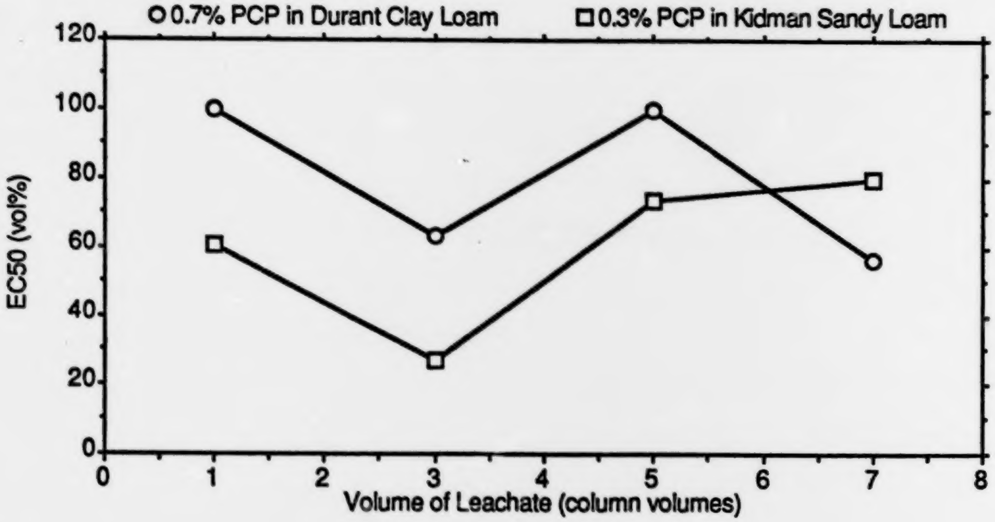

Figure 43. Immobilization of PCP waste as determined by Microtox bioassay evaluation of laboratory column leachate 334 days after waste incorporation into soil. (EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.)

TABLE 38. WASTE/WATER (K_o) PARTITION COEFFICIENTS FOR PAH CONSTITUENTS IN FOUR WASTES

	PCP Sludge Waste		Creosote Sludge Waste		API Separator Sludge		Slop Oil Emulsion Solids	
	K_o	log K_o	K_o	log K_o	K_o	log K_o	K_o	log K_o
Naphthalene	2,700	3.44	3,800	3.58	3,400	3.53	1,500	3.19
Fluorene	9,900	4.00	34,700	4.54	33,100	4.52	18,600	4.27
Phenanthrene	7,500	3.88	3,400	3.53			22,300	4.35
Anthracene	29,200	4.47	81,800	4.91	102,000	5.01	23,700	4.36
Fluoranthene	9,500	3.98	17,900	4.25	101,000	5.00	22,700	4.36
Pyrene	11,200	4.05	700	2.84	134,000	5.13	25,200	4.40
Benz(a)anthracene					118,000	5.07	26,400	4.42
Chrysene	11,400	4.06	70,500	4.85	110,000	5.04	20,300	4.31
Benzo(b)fluoranthene	12,500	4.10	13,700	4.14				
Benzo(k)fluoranthene	6,000	3.78	17,900	4.25	116,000	5.06		
Benzo(a)pyrene	4,000	3.62	17,600	4.25				
Benzo(ghi)perylene								
Dibenz(a,h)anthracene			5,300	3.73				
Indeno(1,2,3)pyrene	3,900	3.600			214,000	5.33		

TABLE 39. PARTITION COEFFICIENTS FOR VOLATILE COMPOUNDS IN API SEPARATOR SLUDGE

	Concentration in			K_h (air/water)		K_o (oil/water)		K_{ao} (air/waste)	
	Air (μg/l)	Water (μg/l)	Waste (mg/kg)	K_h	log K_h	K_o	log K_o	K_{ao}	log K
Benzene	1,700	4,000	4,300	0.44	-0.36	1,100	3.03	4.05×10^{-4}	-3.39
Toluene	1,200	10,000	5,300	0.11	-0.94	500	2.72	2.19×10^{-4}	-3.66
Ethylbenzene	200	800	2,500	0.25	-0.60	3,200	3.50	8.03×10^{-5}	-4.10
p-xylene	230	4,100	3,400	0.06	-1.25	800	2.92	6.80×10^{-5}	-4.17
m-xylene	590	3,400	8,000	0.18	-0.76	2,400	3.38	7.35×10^{-5}	-4.13
o-xylene	240	3,100	3,300	0.08	-1.13	1,000	3.02	7.09×10^{-5}	-4.15
Napthalene	4	900	1,900	4.3×10^{-3}	-2.36	2,200	3.35	1.94×10^{-6}	-5.71

TABLE 40. PARTITION COEFFICIENTS FOR VOLATILE COMPOUNDS IN SLOP OIL EMULSION SOLIDS

	Concentration in			K_h (air/water)		K_o (oil/water)		K_{ao} (air/waste)	
	Air (μg/1)	Water (μg/1)	Waste (mg/kg)	K_h	log K_h	K_o	log K_o	K_{ao}	log K
Benzene	750	850	4,600	0.88	-0.06	5,400	3.73	$1.6x10^{-4}$	-3.79
Toluene	780	10,400	2,800	$7.5x10^{-2}$	-1.12	275	2.44	$2.7x10^{-4}$	-3.56
Ethylbenzene	230	3,800	3,600	$5.9x10^{-2}$	-1.23	900	2.97	$6.3x10^{-5}$	-4.20
p-xylene	260	5,300	4,100	$4.8x10^{-2}$	-1.32	800	2.89	$6.2x10^{-5}$	-4.21
m-xylene	760	15,200	10,400	$5.0x10^{-2}$	-1.30	700	2.84	$7.2x10^{-5}$	-4.14
o-xylene	280	6,800	4,390	$4.2x10^{-2}$	-1.38	600	2.81	$6.5x10^{-5}$	-4.19
Napthalene	9	1,400	1,130	$6.6x10^{-3}$	-2.18	800	2.90	$8.4x10^{-6}$	-5.08

TABLE 41. PARTITION COEFFICIENTS FOR VOLATILE COMPOUNDS IN PENTACHLOROPHENOL WASTE SLUDGE

	Concentration in			K_h (air/water)		K_o (waste/water)		K_{ao} (air/waste)	
	Air (μg/l)	Water (μg/l)	Waste (mg/kg)	K_h	log K_h	K_o	log K_o	K_{ao}	log K
Benzene	5.35	146.4		3.7×10^{-2}	-1.44				
Toluene	8.05	232		3.5×10^{-2}	-1.46				
Ethylbenzene	3.07	58.2		5.3×10^{-2}	-1.28				
p-xylene	5.20	71.2		7.3×10^{-2}	-1.14				
m-xylene	6.11	94.1	27.76	6.5×10^{-2}	-1.19	4,500	3.7	2.20×10^{-4}	-3.66
o-xylene	2.68	64.6	22.06	4.1×10^{-2}	-1.38	8,200	3.9	1.21×10^{-4}	-3.92
Napthalene	90.5	11,600	9700	7.8×10^{-3}	-2.11	107,000	5.0	9.35×10^{-6}	-5.03

TABLE 42. PARTITION COEFFICIENTS FOR VOLATILE COMPOUNDS IN CREOSOTE WASTE SLUDGE

	Concentration in			K_h (air/water)		Ko (waste/water)		K_{ao} (air/waste)	
	Air (µg/l)	Water (µg/l)	Waste (mg/kg)	K_h	log K_h	K_o	log K_o	K_{ao}	log K
Benzene	0.42	8.53		0.05	-1.30				
Toluene	1.10	27.3		0.04	-1.39				
Ethylbenzene	0.61	6.74		0.09	-1.04				
p-xylene	2.53								
m-xyiene	1.50	21.45	107	0.07	-1.16	5000	3.7	1.40×10^{-5}	-4.9
o-xylene	0.79	9.76	9.76	0.08	-1.09	1000	3.0	8.09×10^{-5}	-4.1
Napthalene	50.95	6500	11,000	7.9×10^{-3}	-2.10	1748	3.2	4.50×10^{-6}	-5.4

concentrations of constituents were generally in the ratio of 1:10:10,000 for air:water:waste phases except for naphthalene (1:100:100,000). Therefore, results of partition coefficient studies for the four wastes indicate a two and five log increase in concentration from air to water and from air to waste (oil) phases, respectively.

SUMMARY

Immobilization of hazardous waste as measured by the Microtox assay of laboratory column leachates indicated that little toxicity was exhibited by leachates from petroleum wastes incubated at the high loading rates in Durant clay loam soil and in Kidman sandy loam soil. Leachates produced from creosote and PCP loaded columns exhibited definitive levels of toxicity, thus indicating the potential for generation of WSF extract toxicity that should be considered when determining waste loading rates for the experimental soils used.

Differences in the two experimental soils that may be related to the immobilization of toxic constituents in PCP wastes may be characterized in terms of soil pH and soil organic matter. At the pH of the Durant soil and Kidman soil, 6.6 and 7.9, respectively, PCP is expected to be in the dissociated, ionized form since these pH values are above the pKa value for PCP. PCP is known to be toxic to the Microtox organisms; sodium pentachlorophenate is used as a standard for calibrating the Microtox. PCP would be expected to be more dissociated, and therefore more water soluble, in the leachate from the Kidman soil. Also, the Kidman soil contains less organic matter (0.5 percent) than the Durant soil (2.88 percent). Since organic matter content is related to the capacity of a soil to sorb organic chemicals, it is expected that the Durant soil would be more efficient at treatment, i.e., immobilization of PCP, than Kidman soil. Thus the observed differences between leachate toxicities from the Durant soil and Kidman soil columns may be due to soil characteristics including pH and organic matter content.

Partition coefficients that were determined for PAH and volatile constituents of all four wastes indicated highest partitioning of constituents into the oil or waste phase. Relative concentrations between water and oil or waste phases for PAH constituents were generally 1:1000 to 1:100,000, with the higher ratios observed for the petroleum wastes. Relative concentrations among air:water:waste (oil) phases for volatile constituents were generally 1:100:100,000. The oil or waste phase demonstrated greatest partitioning for both semivolatile and volatile constituents present in all four wastes evaluated.

REFERENCES

Bulman, T. L., S. Lesage, P. J. A. Fowles, and M. D. Webber. 1985. The persistence of polynuclear aromatic hydrocarbons in soil. PACE Report No. 85-2, Petroleum Assoc. for Conservation of the Canadian Environ. Ottawa, Ontario.

Jury, W. A., W. F. Spencer, and W. J. Farmer. 1983. Behavior assessment model for trace organics in soil: Model description. J. Environ. Qual. 12:558-564.

Kleinbaum, D. G. and L. L. Kupper. 1978. Applied regression analysis and other multivariable methods. Duxbury Press, North Scituate, MA.

Short, T. E. 1986. Modeling of processes in the unsaturated zone, p. 211-240. In: R. C. Loehr and J. F. Malina, Jr., eds. Land treatment: A hazardous waste mangement alternative. Water Reosurces Symp. No. 13, Center for Research in Water REsources, The Univ. of Texas at Austin, TX.

Sims, R. C. 1982. Land treatment of polynuclear aromatic compounds. PhD Dissertation. Dept. Biol. Agr. Eng., No. Carolina State Univ., Raleigh, NC.

Sims, R. C., and M. R. Overcash. 1983. Fate of polynuclear aromatic compounds (PNAs) in soil-plant systems. Residue Rev. 88:1-68.

SPSS Inc. 1986. SPSSX User's guide. Second edition. McGraw-Hill Book Company, New York, NY. 988 p.

U.S. EPA. 1982. Test methods for evaluating solid waste, physical/chemical methods. 2nd Ed. SW-846. U.S. Environmental Protection Agency, Washington, D.C.

U. S. EPA. 1986b. Permit guidance manual on hazardous waste land treatment demonstrations. Final Draft. Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Washington, D.C.

APPENDIX A

RESULTS OF LABORATORY ANALYSES

TABLE A-1. RESULTS FOR OIL AND GREASE VALUES WITH INCUBATION TIME AT LOW SOIL MOISTURE CONTENT FOR CREOSOTE WASTE MIXED WITH DURANT CLAY LOAM SOIL

Sample Time (day)	Oil and Grease (mg/kg)					
	Replicate Reactors					
	1	2	3	$\bar{x}$	SD	CV (%)
	Load Rate (%waste wet/soil dry) 0.7 %					
0	2600	2700	2600	2600	58	2.2
37	2000	2600	2600	2400	390	15.6
143	2800	2600	2700	2700	100	3.7
167	1600	3100	3000	2600	840	32.7
234	3100	2200	2300	2500	490	19.5
	Load Rate (%waste wet/soil dry) 1.0 %					
0	3600	3200	3200	3300	230	6.9
37	3000	2700	3000	2900	170	6.0
143	5000	3400	3300	3900	950	24.5
167	3100	3500	2200	2900	670	22.7
234	2500	3000	1500	2300	760	32.7
	Load Rate (%waste wet/soil dry) 1.3 %					
0	4400	3800	4300	4100	310	7.4
37	3000	4700	3800	3800	850	22.2
143	3900	3800	4600	4100	440	10.6
167	2500	4500	6400	4500	2000	43.7
234	2600	3600	4000	3400	720	21.2
	Control					
0	200	400	200			
37	300	300	300			
143	N/A*	N/A	N/A			
167	500	700	600			
234	500	300	400			

*N/A - no analysis.

TABLE A-2. RESULTS FOR OIL AND GREASE VALUES WITH INCUBATION TIME AT LOW SOIL MOISTURE CONTENT FOR CREOSOTE WASTE MIXED WITH KIDMAN SANDY LOAM SOIL

Sample Time (day)	Oil and Grease (mg/kg)					
	Replicate Reactors					
	1	2	3	$\bar{x}$	SD	CV (%)
			Load Rate (%waste wet/soil dry) 0.4 %			
0	1400	1600	1400	1500	1200	7.9
29	1100	7000	1900	3400	3200	95.2
130	1200	1500	1100	1300	210	16.4
158	1300	1500	1300	1400	120	8.5
225	1300	1700	1500	1500	200	13.3
			Load Rate (%waste wet/soil dry) 0.7 %			
0	2500	2100	2100	2200	230	10.3
29	3100	2300	6900	4100	2500	60.0
130	2100	2100	1900	2000	120	5.7
158	2100	2200	2000	2100	100	4.8
225	2300	2300	2200	2300	58	2.6
			Load Rate (%waste wet/soil dry) 1.0 %			
0	4000	3100	3000	3400	550	16.4
29	3200	3400	2100	2900	700	24.1
130	2800	2900	2900	2900	58	2.0
158	3000	3100	3300	3100	150	4.9
225	2900	3000	2500	2800	260	9.5
			Control			
0	200	300	100			
29	N/A*	N/A	N/A			
130	100	100	100			
158	100	100	200			
225	300	300	0			

*N/A - no analysis.

TABLE A-3. RESULTS FOR OIL AND GREASE VALUES WITH INCUBATION TIME AT LOW SOIL MOISTURE CONTENT FOR PCP WASTE MIXED WITH DURANT CLAY LOAM SOIL

Sample Time (day)	Oil and Grease (mg/kg)					
	Replicate Reactors					
	1	2	3	$\bar{x}$	SD	CV (%)
			Load Rate (%waste wet/soil dry) 0.3 %			
0	2500	2200	1900	1900	450	24.1
28	1100	2000	2200	1400	750	53.5
116	1300	1600	1200	1400	320	23.8
140	1200	1400	1300	1400	210	14.4
207	1000	1000	1100	1200	180	15.5
			Load Rate (%waste wet/soil dry) 0.5 %			
0	3500	1900	2900	2800	810	29.2
28	1700	1400	4300			
116	1300	1500	3100	2000	990	50.2
140	2300	1500	1900	2300	800	34.8
207	1500	1100	2000	1500	450	29.4
			Load Rate (%waste wet/soil dry) 0.7 %			
0	4600	4200	4100	4300	260	6.2
28	2800	2600	4200	3200	870	27.2
116	2800	3700	3100	3200	460	14.3
140	3200	3100	2900	3100	170	5.6
207	2200	2400	2500	2400	150	6.5
			Control			
0	300	200	200			
28	300	200	300			
116	300	200	200			
140	500	500	500			
207	200	300	200			

TABLE A-4. RESULTS FOR OIL AND GREASE VALUES WITH INCUBATION TIME AT LOW SOIL MOISTURE CONTENT FOR PCP WASTE MIXED WITH KIDMAN SANDY LOAM SOIL

Sample Time (day)	Oil and Grease (mg/kg)					
	Replicate Reactors					
	1	2	3	x̄	SD	CV (%)
			Load Rate (%waste wet/soil dry) 0.075 %			
0	500	400	600	500	100	20.0
28	500	600	900	670	210	31.2
112	500	500	400	470	58	12.4
140	400	400	400	400	0	0
207	500	600	500	530	58	10.8
			Load Rate (%waste wet/soil dry) 0.15 %			
0	800	600	800	1400	560	40.0
28	1000	900	1500	1100	320	28.4
112	600	700	700	670	58	8.7
140	700	1000	700	800	170	1.7
207	800	800	800	800	0	0
			Load Rate (%waste wet/soil dry) 0.3 %			
0	1600	1200	1900	1600	350	22.4
28	1500	1500	1000	1000	810	78.2
112	1200	1200	1200	1200	0	0
140	1400	1500	1800	1600	210	13.3
207	1200	1400	1400	1300	120	8.7
			Control			
0	100	200	100			
28	200	200	250			
112	100	200	100			
140	400	300	500			
207	100	100	100			

TABLE A-5. RESULTS FOR OIL AND GREASE VALUES WITH INCUBATION TIME AT LOW SOIL MOISTURE CONTENT FOR API SEPARATOR SLUDGE WASTE MIXED WITH DURANT CLAY LOAM SOIL

Sample Time (day)	Oil and Grease (mg/kg)					
	Replicate Reactors					
	1	2	3	$\bar{x}$	SD	CV (%)
			Load Rate (%waste wet/soil dry) 6%			
0	28000	12000	8000	16000	11000	68.1
37	18000	15000	16000	16000	1500	9.4
143	39000	42000	20000	34000	12000	35.4
167	10000	13000	17000	13000	3500	26.3
234	16000	15000	16000	16000	580	3.7
			Load Rate (%waste wet/soil dry) 9%			
0	27000	14000	16000	19000	7000	36.8
37	27000	20000	23000	23000	3500	15.1
143	29000	20000	21000	23000	4900	21.1
167	26000	18000	22000	22000	4000	18.2
234	23000	19000	19000	24000	5000	21.3
			Load Rate (%waste wet/soil dry) 12%			
0	36000	20000	18000	25000	9900	40.0
37	30000	33000	30000	31000	1700	5.6
143	30000	21000	28000	26000	4700	18.0
167	31000	30000	28000	30000	1500	5.2
234	28000	29000	27000	28000	1000	3.6
			Control			
0	400	300	400			
37	300	200	100			
143	330	240	270			
167	300	100	200			
234	300	200	300			

TABLE A-6. RESULTS FOR OIL AND GREASE VALUES WITH INCUBATION TIME AT LOW SOIL MOISTURE CONTENT FOR API SEPARATOR SLUDGE WASTE MIXED WITH KIDMAN SANDY LOAM SOIL

Sample Time (day)	Oil and Grease (mg/kg)					
	Replicate Reactors					
	1	2	3	$\bar{x}$	SD	CV (%)
			Load Rate (%waste wet/soil dry) 6%			
0	22000	16000	15000	17000	4000	23.3
29	19000	14000	17000	17000	2500	15.1
130	20000	15000	17000	17000	2500	14.5
158	22000	14000	18000	18000	4600	25.5
225	17000	13000	17000	16000	2300	14.7
			Load Rate (%waste wet/soil dry) 9%			
0	18000	26000	17000	20000	4900	24.3
29	23000	28000	20000	24000	4000	17.1
130	24000	27000	17000	23000	5300	23.0
158	23000	27000	19000	26000	2100	8.3
225	22000	23000	17000			
			Load Rate (%waste wet/soil dry) 12%			
0	32000	27000	30000	30000	2500	8.5
29	32000	28000	33000	31000	2600	8.5
130	24000	29000	29000	27000	2900	10.6
158	32000	24000	23000	26000	4900	18.7
225	26000	26000	30000	27000	2300	8.5
			Control			
0	200	300	100			
29	120	100	100			
130	100	100	100			
158	100	200	100			
225	400	400	400			

TABLE A-7. RESULTS FOR OIL AND GREASE VALUES WITH INCUBATION TIME AT LOW SOIL MOISTURE CONTENT FOR SLOP OIL WASTE MIXED WITH DURANT CLAY LOAM SOIL

Sample Time (day)	Oil and Grease (mg/kg)					
	Replicate Reactors					
	1	2	3	$\bar{x}$	SD	CV (%)
			Load Rate (%waste wet/soil dry) 8%			
0	36000	33000	47000	39000	7400	19.1
28	48000	51000	53000	51000	2500	5.0
105	51000	50000	48000	50000	1500	3.1
129	51000	46000	48000	48000	2500	5.2
196	48000	47000	44000	46000	2100	4.5
			Load Rate (%waste wet/soil dry) 12%			
0	34000	64000	45000	48000	15000	31.8
28	58000	58000	49000	55000	5200	9.5
105	58000	59000	61000	59000	1500	2.6
129	56000	61000	58000	58000	2500	4.3
196	53000	N/A*	54000	54000	710	1.3
			Load Rate (%waste wet/soil dry) 14%			
0	47000	41000	67000	52000	14000	26.4
28	78000	76000	90000	81000	7600	9.3
105	77000	78000	88000	81000	6100	7.5
129	84000	81000	87000	84000	3000	3.6
196	73000	75000	N/A	74000	1400	1.9
			Control			
0	300	200	3000			
28	400	500	400			
105	100	200	200			
129	400	200	200			
196	400	400	500			

*N/A - no analysis.

TABLE A-8. RESULTS FOR OIL AND GREASE VALUES WITH INCUBATION TIME AT LOW SOIL MOISTURE CONTENT FOR SLOP OIL WASTE MIXED WITH KIDMAN SANDY LOAM SOIL

Sample Time (day)	Oil and Grease (mg/kg)					
	Replicate Reactors					
	1	2	3	$\bar{x}$	SD	CV (%)
			Load Rate (%waste wet/soil dry) 6%			
0	43000	37000	36000	39000	3800	9.8
28	59000	58000	36000	51000	13000	25.5
103	35000	35000	25000	32000	5800	18.2
129	36000	34000	34000	35000	1200	3.3
196	32000	32000	34000	33000	1200	3.5
			Load Rate (%waste wet/soil dry) 8%			
0	46000	40000	52000	46000	6000	13.0
28	64000	64000	62000	63000	1200	1.8
103	43000	43000	42000	43000	580	1.4
129	42000	44000	36000	41000	4200	10.2
196	38000	40000	39000	39000	1200	3.0
			Load Rate (%waste wet/soil dry) 12%			
0	34000	54000	70000	53000	18000	34.3
28	65000	73000	72000	70000	4400	6.2
103	58000	60000	58000	59000	1200	2.0
129	66000	61000	55000	61000	5500	9.1
196	55000	52000	55000	54000	1500	2.9
			Control			
0	300	400	200			
28	300	400	300			
103	200	100	100			
129	200	200	200			
196	300	300	300			

TABLE A-9. OIL AND GREASE DATA WITH INCUBATION TIME FOR API SEPARATOR SLUDGE WASTE APPLIED AT VARIOUS RATES TO DURANT CLAY LOAM SOIL AT 1 BAR SOIL MOISTURE

Incubation Time (days)	Oil and Grease (mg/kg soil) Loading Rates	
	M/M*	H/NR+
0	36000	21000
35	-#	-
70	23000	14000
98	-	-

*M/M = originally loaded at medium rate (9%), reloaded at medium rate.
+H/NR = originally loaded at high rate (12%), not reloaded.
#- = no sample taken.

TABLE A-10. OIL AND GREASE DATA WITH INCUBATION TIME FOR API SEPARATOR SLUDGE WASTE APPLIED AT VARIOUS RATES TO KIDMAN SANDY LOAM SOIL AT 1/3 BAR SOIL MOISTURE

Incubation Time (days)	Oil and Grease (mg/kg soil) Loading Rates			
	M/M*	L/H+	N/H#	H/NR**
0	35000	64000	40000	27000
35	-++	-	-	-
70	32000	51000	30000	23000
98	-	-	-	-

*M/M = originally loaded at medium rate (9%), reloaded at medium rate.
+L/H = originally loaded at low rate (6%), reloaded at high rate (12%).
#N/H = nonacclimated soil loaded at high rate (12%).
**H/NR = originally loaded at high rate (12%), not reloaded.
++- = no sample taken.

TABLE A-11. OIL AND GREASE DATA WITH INCUBATION TIME FOR SLOP OIL WASTE APPLIED AT VARIOUS RATES TO DURANT CLAY LOAM SOIL AT 1 BAR SOIL MOISTURE

Incubation Time (days)	Oil and Grease (mg/kg soil) Loading Rates	
	M/M*	H/NR+
0	150000	64000
39	-#	-
74	130000	49000
102	-	-

*M/M = originally loaded at medium rate (12%), reloaded at medium rate.
+H/NR = originally loaded at high rate (14%), not reloaded.
#- = no sample taken.

TABLE A-12. OIL AND GREASE DATA WITH INCUBATION TIME FOR SLOP OIL WASTE APPLIED AT VARIOUS RATES TO KIDMAN SANDY LOAM SOIL AT 1/3 BAR SOIL MOISTURE

Incubation Time (days)	Oil and Grease (mg/kg soil) Loading Rates			
	M/M*	L/H+	N/H#	H/NR**
0	85000	69000	74000	49000
39	-++	-	-	-
74	85000	120000	63000	40000
102	-	-	-	-

*M/M = originally loaded at medium rate (8%), reloaded at medium rate.
+L/H = originally loaded at low rate (6%), reloaded at high rate (12%).
#N/H = nonacclimated soil loaded at high rate (12%).
**H/NR = originally loaded at high rate (12%), not reloaded.
++- = no sample taken.

TABLE A-13. OIL AND GREASE DATA WITH INCUBATION TIME FOR DURANT CLAY LOAM SOIL CONTROL AT 1 BAR SOIL MOISTURE AND KIDMAN SANDY LOAM SOIL CONTROL AT 1/3 BAR SOIL MOISTURE

Incubation Time (days)	Oil and Grease (mg/kg soil)	
	Durant Clay Loam	Kidman Sandy Loam
0	100	100
21	-*	-
46	500	200
74	-	-

*- = no sample taken.

TABLE A-14 . RESULTS FOR PAH ANALYSIS AT LOW SOIL MOISTURE CONTENT FOR API SEPARATOR SLUDGE WASTE MIXED WITH DURANT CLAY LOAM SOIL IMMEDIATELY AFTER WASTE ADDITION

PAH (mg/kg soil)	Load Rate (% waste wet/soil dry)	
	6%	12%
Naphthalene	40.7	66.8
Fluorene	0.2*	0.8
Phenanthrene	56.4	97.6
Anthracene	0.2*	0.2*
Fluoranthene	340	680
Pyrene	380	750
Benz(a)anthracene	91.4	170
Chrysene	55.0	52.3
Benzo(b)fluoranthene	0.2*	69.5
Benzo(k)fluoranthene	0.2*	ND+
Benzo(a)pyrene	0.2*	16.8
Benzo(ghi)perylene	0.6*	0.6*
Dibenz(a,h)anthracene	1.3*	ND+
Indeno(1,2,3)pyrene	0.3*	5.1

*Detection limit.

+ND = Not detected (no peak present).

TABLE A-15. RESULTS FOR PAH ANALYSIS AT LOW SOIL MOISTURE CONTENT FOR API SEPARATOR SLUDGE WASTE MIXED WITH DURANT CLAY LOAM SOIL AFTER 167 DAYS INCUBATION TIME

PAH (mg/kg soil)	Load Rate (% waste wet/soil dry)	
	6%	12%
Naphthalene	0.30*	0.30*
Fluorene	0.2*	1.5
Phenanthrene	26.7	120
Anthracene	0.2*	0.2*
Fluoranthene	250	1100
Pyrene	270	1300
Benz(a)anthracene	83.8	230
Chrysene	22.0	110
Benzo(b)fluoranthene	3.2	160
Benzo(k)fluoranthene	0.2*	0.2*
Benzo(a)pyrene	0.2*	120
Benzo(ghi)perylene	0.6*	0.6*
Dibenz(a,h)anthracene	1.3*	1.3*
Indeno(1,2,3)pyrene	0.3*	5.9

*Detection limit.

TABLE A-16. RESULTS FOR PNA ANALYSIS AT LOW SOIL MOISTURE CONTENT FOR API SEPARATOR SLUDGE WASTE MIXED WITH KIDMAN SANDY LOAM SOIL IMMEDIATELY AFTER WASTE ADDITION

PNA (mg/kg soil)	Load Rate (% waste wet/soil dry)	
	6%	12%
Naphthalene	38.4	61.3
Fluorene	0.2[*]	0.2[*]
Phenanthrene	50.4	80.3
Anthracene	0.2[*]	0.2[*]
Fluoranthene	310	220
Pyrene	330	580
Benz(a)anthracene	85.9	120
Chrysene	21.2	34.4
Benzo(b)fluoranthene	22.1	36.7
Benzo(k)fluoranthene	ND[+]	ND
Benzo(a)pyrene	ND	ND
Benzo(ghi)perylene	0.6[*]	0.6[*]
Dibenz(a,h)anthracene	1.3[*]	1.3[*]
Indeno(1,2,3)pyrene	0.3[*]	17.0

[*] Detection limit.

[+] ND = Not detected (peak not present).

TABLE A-17. RESULTS FOR PAH ANALYSIS AT LOW SOIL MOISTURE CONTENT FOR API SEPARATOR SLUDGE WASTE MIXED WITH KIDMAN SANDY LOAM SOIL AFTER 158 DAYS INCUBATION TIME

PAH (mg/kg soil)	Load Rate (% waste wet/soil dry)	
	6%	12%
Naphthalene	0.30*	0.30*
Fluorene	0.26*	0.2*
Phenanthrene	41.7	89.2
Anthracene	0.2*	0.2*
Fluoranthene	280	640
Pyrene	310	730
Benz(a)anthracene	81.5	160
Chrysene	19.3	50.0
Benzo(b)fluoranthene	28.2	51.2
Benzo(k)fluoranthene	0.2*	ND+
Benzo(a)pyrene	31.8	0.2*
Benzo(ghi)perylene	0.6*	0.6*
Dibenz(a,h)anthracene	ND	ND
Indeno(1,2,3)pyrene	ND	2.9

*Detection limit.

+ND = Not detected (peak not present).

TABLE A-18. RESULTS FOR PNA ANALYSIS AT LOW SOIL MOISTURE CONTENT FOR SLOP OIL WASTE MIXED WITH DURANT CLAY LOAM SOIL IMMEDIATELY AFTER WASTE ADDITION

PAH (mg/kg soil)	Load Rate (% waste wet/soil dry)		
	8%	12%	14%
Naphthalene	190	220	460
Fluorene	7.6	73.4	86.8
Phenanthrene	170	600	470
Anthracene	0.2*	70.0	10.0
Fluoranthene	1100	2000	3300
Pyrene	1200	ND+	3900
Benz(a)anthracene	59.0	ND	390
Chrysene	11.0	ND	160
Benzo(b)fluoranthene	18.5	0.2*	69.4
Benzo(k)fluoranthene	0.2*	0.2*	8.8
Benzo(a)pyrene	ND	57.8	13.8
Benzo(ghi)perylene	ND	0.6*	9.5
Dibenz(a,h)anthracene	ND	1.8*	1.8*
Indeno(1,2,3-d)pyrene	ND	0.3*	9.9

*Detection limit.

+ND = Not detected (peak not present).

TABLE A-19. RESULTS FOR PAH ANALYSIS AT LOW SOIL MOISTURE CONTENT FOR SLOP OIL WASTE MIXED WITH DURANT CLAY LOAM SOIL AFTER 129 DAYS INCUBATION TIME

PAH (mg/kg soil)	Load Rate (% waste wet/soil dry)		
	8%	12%	14%
Naphthalene	56.8	27.8	74.6
Fluorene	13.0	16.1	54.9
Phenanthrene	180	130	380
Anthracene	0.2*	9.8	0.2*
Fluoranthene	1300	1200	2800
Pyrene	1500	120	3300
Benz(a)anthracene	140	120	350
Chrysene	56.7	0.2*	140
Benzo(b)fluoranthene	38.0	0.2*	65.8
Benzo(k)fluoranthene	0.2*	0.2*	0.2*
Benzo(a)pyrene	5.0	1.4	0.2*
Benzo(ghi)perylene	0.6*	0.6*	0.6*
Dibenz(a,h)anthracene	1.3*	1.3*	1.3*
Indeno(1,2,3)pyrene	0.3*	0.3*	0.3*

*Detection limit.

TABLE A-20. RESULTS FOR PAH ANALYSIS AT LOW SOIL MOISTURE CONTENT FOR SLOP OIL WASTE MIXED WITH KIDMAN SANDY LOAM SOIL IMMEDIATELY AFTER WASTE ADDITION

PAH (mg/kg soil)	Load Rate (% waste wet/soil dry)	
	8%	12%
Naphthalene	150	350
Fluorene	30.3	65.0
Phenanthrene	230	360
Anthracene	32.9	0.2*
Fluoranthene	3200	2600
Pyrene	4100	3000
Benz(a)anthracene	270	320
Chrysene	160	130
Benzo(b)fluoranthene	0.2*	72.9
Benzo(k)fluoranthene	0.2*	0.2*
Benzo(a)pyrene	0.2*	0.2*
Benzo(ghi)perylene	0.6*	0.6*
Dibenz(a,h)anthracene	1.3*	1.3*
Indeno(1,2,3)pyrene	0.3*	0.3*

*Detection limit.

TABLE A-21. RESULTS FOR PAH ANALYSIS AT LOW SOIL MOISTURE CONTENT FOR SLOP OIL WASTE MIXED WITH KIDMAN SANDY LOAM SOIL AFTER 131 DAYS INCUBATION TIME

PAH (mg/kg soil)	Load Rate (% waste wet/soil dry)	
	8%	12%
Naphthalene	37.8	96.0
Fluorene	35.9	31.6
Phenanthrene	260	300
Anthracene	22.9	0.2*
Fluoranthene	7200	2200
Pyrene	0.2*	2600
Benz(a)anthracene	0.8*	280
Chrysene	240	110
Benzo(b)fluoranthene	0.2*	54.0
Benzo(k)fluoranthene	0.2*	0.2*
Benzo(a)pyrene	25.9	0.2*
Benzo(ghi)perylene	0.6*	0.6*
Dibenz(a,h)anthracene	1.3*	1.3*
Indeno(1,2,3)pyrene	0.3*	0.3*

*Detection limit.

TABLE A-22. RESULTS FOR PAH ANALYSIS AT LOW SOIL MOISTURE CONTENT FOR CREOSOTE WASTE MIXED WITH DURANT CLAY LOAM SOIL IMMEDIATELY AFTER WASTE ADDITION

	PAH (mg/kg soil)								
	Load Rate (% waste wet/soil dry)								
	0.7%			1.0%			1.3%		
	Replicate reactors								
	1	2	3	1	2	3	1	2	3
Naphthalene	*								
Fluorene	9.6	7.4	9.0	13.5	11.4	12.3		17.3	14.8
Phenanthrene	33.4	25.9	29.9	47.2	39.7	43.3		55.9	50.6
Anthracene	5.6	2.4	2.4	6.7	4.6	8.2		10.8	11.8
Fluoranthene	30.3	23.6	28.0	43.1	36.4	39.6		52.4	46.8
Pyrene	24.0	19.0	22.5	34.3	28.8	31.4		41.7	36.7
Benzo(a)anthracene	2.8	2.3	2.8	4.3	3.7	4.0		5.7	4.9
Chrysene	3.2	2.7	3.4	4.9	4.0	4.4		6.0	5.5
Benzo(b)fluoranthene	1.1	1.1	1.3	2.0	1.6	1.8	1.6	2.6	2.2
Benzo(k)fluoranthene	+	1.0	1.2	1.4	1.0	1.2	ND#	1.8	1.6
Benzo(a)pyrene	1.3	1.4	1.4	1.7	1.5	1.7	ND	2.1	1.9
Benzo(ghi)perylene							0.6+	0.8	1.0
Dibenz(a,h)anthracene							2.1	1.1	1.1
Indeno(1,2,3-cd)pyrene	0.6	0.5	0.7	0.5	0.5	0.8		0.7	0.6

*No data indicate insufficient quantitative information to calculate half-life.
+Detection limit.
#ND = Not detected (peak not present).

TABLE A-22. CONTINUED

	PAH (mg/kg soil)								
	Load Rate (% waste wet/soil dry)								
	0.7%			1.0%			1.3%		
	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
Naphthalene	0.8	0.6	70	0.4	0.1	32	18.0	2.6	15
Fluorene	8.7	1.1	13	12.0	1.1	9	47.0	54.0	115
Phenanthrene	30	3.8	13	43.0	3.8	9	39.0	25.0	64
Anthracene	3.5	1.8	53	6.5	1.8	28	7.6	6.4	85
Fluoranthene	27.0	3.4	13	40.0	3.4	8	37.0	21.0	57
Pyrene	19.0	7.2	38	32.0	2.8	9	32.0	12.0	39
Benzo(a)anthracene	2.6	0.3	11	4.0	0.3	8	3.8	2.7	70
Chrysene	3.1	0.4	12	4.1	0.3	7	4.2	2.7	64
Benzo(b)fluoranthene	1.2	0.1	10	1.8	0.2	11	2.1	0.5	24
Benzo(k)fluoranthene	0.8	0.6	70	1.2	0.2	17	1.2	0.9	75
Benzo(a)pyrene	1.4	0.1	4	1.6	0.1	7	1.4	1.1	78
Benzo(ghi)perylene	0.6	0	0	5.6	0	0	0.8	0.2	28
Dibenz(a,h)anthracene	1.3	0	0	1.3	0	0	1.4	0.6	40
Indeno(1,2,3-cd)pyrene	0.6	0.1	17	0.6	0.2	29	0.5	0.2	40

TABLE A-23. RESULTS FOR PAH ANALYSIS AT LOW SOIL MOISTURE CONTENT FOR CREOSOTE WASTE MIXED WITH DURANT CLAY LOAM SOIL AFTER 37 DAYS INCUBATION TIME

	PAH (mg/kg soil)								
	Load Rate (% waste wet/soil dry)								
	0.7%			1.0%			1.3%		
	Replicate reactors								
	1	2	3	1	2	3	1	2	3
Naphthalene	*						8.6		11.4
Fluorene	8.5	8.2	8.6	7.8	11.4	13.7	14.7	12.1	14.6
Phenanthrene	28.0	29.6	30.0	28.1	38.6	45.6	51.5	40.7	47.3
Anthracene		2.6	1.8	5.3	5.1	6.4	18.6	5.3	6.1
Fluoranthene	23.2	27.8	28.6	26.6	37.4	43.6	48.3	39.3	45.2
Pyrene	17.4	21.5	20.8	20.0	30.0	34.6	37.9	31.0	35.4
Benzo(a)anthracene	1.8	2.2	2.0	2.1	3.9	4.6	4.9	4.1	4.6
Chrysene	1.9	2.4	2.4		3.9	4.8	5.1	4.1	5.0
Benzo(b)fluoranthene	0.7	0.9	0.8	1.1	1.5	2.0	1.7	1.8	2.2
Benzo(k)fluoranthene	0.8	0.9	0.9	0.8	1.4	1.7	1.8	1.5	1.7
Benzo(a)pyrene	1.4	1.4	0.2+	1.6	1.8	1.8	1.9	1.8	1.9
Benzo(ghi)perylene				0.6*	0.9	0.6*	0.6*	0.9	0.4
Dibenz(a,h)anthracene							1.3*	1.4	1.3*
Indeno(1,2,3-cd)pyrene	0.6	0.6	0.9	ND#	0.6	0.7		0.6	0.6

*No data indicate insufficient quantitative information to calculate half-life.
+Detection limit.
#ND = Not detected (peak not present).

TABLE A-23. CONTINUED

	PAH (mg/kg soil)								
	Load Rate (% waste wet/soil dry)								
	0.7%			1.0%			1.3%		
	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
Naphthalene	7.3	4.5	62	3.9	3.6	93	6.8	5.8	85
Fluorene	8.4	2.1	3	110	3.0	27	140	1.5	11
Phenanthrene	290	1.1	4	370	8.8	24	47	5.4	12
Anthracene	7.0	8.3	119.	5.6	7.0	13	100	7.5	75
Fluoranthene	270	2.9	11	360	8.6	24	440	4.6	10
Pyrene	200	2.2	11	280	7.5	27	350	3.5	10
Benzo(a)anthracene	2.0	2.0	10	3.5	1.3	38	4.5	4.0	9
Chrysene	2.2	3.5	16	3.7	1.2	33	4.7	5.5	12
Benzo(b)fluoranthene	8.0	1.0	13	1.4	6.0	42	1.9	2.6	14
Benzo(k)fluoranthene	8.7	0.6	7	1.3	4.0	30	1.7	1.5	9
Benzo(a)pyrene	1.0	0.7	73	1.3	1.0	76	1.9	0.1	3
Benzo(ghi)perylene	0.5	0.4	6	0.6	0	0	0.6	0.3	41
Dibenz(a,h)anthracene							1.3	0.1	6
Indeno(1,2,3-cd)pyrene	0.7	0.2	25	0.8	0.1	15	0.7	0.1	17

TABLE A-24. RESULTS FOR PAH ANALYSIS AT LOW SOIL MOISTURE CONTENT FOR CREOSOTE WASTE MIXED WITH DURANT CLAY LOAM SOIL AFTER 167 DAYS INCUBATION TIME

PAH (mg/kg soil)	Load Rate (% waste wet/soil dry)		
	0.7%	1.0%	1.3%
Naphthalene	120	0.30*	+
Fluorene	4.8	7.9	
Phenanthrene			
Anthracene			
Fluoranthene		30.4	
Pyrene		26.8	
Benz(a)anthracene		0.8*	
Chrysene		4.3	
Benzo(b)fluoranthene		1.6	
Benzo(k)fluoranthene	0.2*	0.2*	
Benzo(a)pyrene	0.2*	0.2*	
Benzo(ghi)perylene		0.6*	0.6*
Dibenz(a,h)anthracene			1.3*
Indeno(1,2,3)pyrene	0.3*	0.3*	

*Detection limit.

+No data indicate insufficient quantitative information to calculate half-life.

TABLE A-25. RESULTS FOR PAH ANALYSIS AT LOW SOIL MOISTURE CONTENT FOR CREOSOTE WASTE MIXED WITH KIDMAN SANDY LOAM SOIL IMMEDIATELY AFTER WASTE ADDITION

	PAH (mg/kg soil)								
	Load Rate (% waste wet/soil dry)								
	0.4%			0.7%			1.0%		
	Replicate reactors								
	1	2	3	1	2	3	1	2	3
Naphthalene	0.7	3.1	0.3	2.8	3.9	4.5	5.1	2.2	2.8
Fluorene	4.8	5.6	3.8	10.5	9.5	10.6	14.2	8.8	7.7
Phenanthrene	15.6	20.6	14.4	32.5	30.5	35.2	42.9	28.9	25.9
Anthracene	0.9	2.3	0.2	5.4	5.5	5.1	6.3	4.2	2.7
Fluoranthene	15.0	18.3	12.0	31.7	29.3	31.3	40.1	28.7	22.8
Pyrene	11.1	15.5	11.4	24.0	23.5	29.8	31.9	22.7	19.5
Benzo(a)anthracene	1.0	1.4	0.8*	2.9	3.1	3.2	4.0	2.7	1.8
Chrysene	1.3	1.6	2.5	3.2	3.1	3.7	4.0	2.8	2.0
Benzo(b)fluoranthene	0.7	0.9	0.5	1.4	1.4	1.5	1.6	1.2	0.6
Benzo(k)fluoranthene	0.6	0.7	0.5	1.2	1.4	1.3	1.4	0.9	0.8
Benzo(a)pyrene	1.4	1.2	1.1	1.5	1.7	1.7	1.7	1.3	1.4
Benzo(ghi)perylene	0.6*	0.6*	0.6*	0.1	1.2	0.6	0.6*	0.6*	0.6*
Dibenz(a,h)anthracene	+						1.3*	1.3*	1.3*
Indeno(1,2,3-cd)pyrene	0.7	0.5	0.6	0.5	0.7	0.6	0.5	0.5	0.5

*Detection limit.

+No data indicate insufficient quantitative information to calculate half-life.

TABLE A-25. CONTINUED

	PAH (mg/kg soil)								
	Load Rate (% waste wet/soil dry)								
	0.4%			0.7%			1.0%		
	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
Naphthalene	1.4	1.5	111	3.7	8.6	23	3.4	1.5	46
Fluorene	4.7	9.0	19	100	6.1	6	100	3.5	34
Phenanthrene	170	3.3	20	330	2.4	7	330	9.1	28
Anthracene	1.1	1.1	94	5.3	2.1	4	4.4	1.8	41
Fluoranthene	150	3.2	21	310	1.3	4	310	8.8	29
Pyrene	130	2.5	19	260	3.5	14	250	6.4	26
Benzo(a)anthracene	1.1	3.3	31	3.1	1.5	5	2.8	1.1	39
Chrysene	1.8	6.2	35	3.3	3.2	10	2.9	1.0	34
Benzo(b)fluoranthene	7.0	2.0	29	1.4	0.6	4	1.3	5.0	44
Benzo(k)fluoranthene	6.0	1.0	17	1.3	1.0	8	1.0	3.2	31
Benzo(a)pyrene	1.2	1.5	12	1.6	1.2	7	1.5	2.1	14
Benzo(ghi)perylene	5.6	0	0	6.3	5.5	87	5.6	0	0
Dibenz(a,h)anthracene	1.3	0	0	1.3	0	0	1.3	0	0
Indeno(1,2,3-cd)pyrene	6.0	1.0	17	6.0	1.0	17	5.0	0	0

TABLE A-26. RESULTS FOR PAH ANALYSIS AT LOW SOIL MOISTURE CONTENT FOR CREOSOTE WASTE MIXED WITH KIDMAN SANDY LOAM SOIL AFTER 29 DAYS INCUBATION TIME

	PAH (mg/kg soil)								
	Load Rate (% waste wet/soil dry)								
	0.4%			0.7%			1.0%		
	Replicate reactors								
	1	2	3	1	2	3	1	2	3
Naphthalene	0.8	0.3*	4.8	2.9	2.1	2.4	1.6	10.8	5.7
Fluorene	4.2	3.7	4.1	7.9	6.8	7.7	12.1	11.0	7.4
Phenanthrene	16.0	13.5	14.8	27.4	27.9	25.3	40.9	37.1	27.4
Anthracene	0.4	3.0	0.7	3.7	2.1	8.4	5.2	4.9	5.8
Fluoranthene	14.4	12.5	13.2	26.7	25.9	22.7	41.0	35.1	24.9
Pyrene	11.3	9.9	10.2	21.2	20.1	17.4	32.3	27.8	19.7
Benzo(a)anthracene	1.1	0.9	0.9	2.6	2.2	2.0	4.0	3.6	2.4
Chrysene	1.4	1.3	1.2	2.7	3.0	2.6	5.0	4.0	2.8
Benzo(b)fluoranthene	0.5	0.7	0.5	1.2	1.1	1.0	1.9	1.5	1.2
Benzo(k)fluoranthene	0.6	0.5	0.6	1.1	0.8	0.8	1.7	1.3	0.8
Benzo(a)pyrene	1.1	1.1	1.1	1.4	1.1	1.2	1.9	1.6	1.3
Benzo(ghi)perylene	0.6	1.6	0.6*	0.6*	0.6*	0.6*	1.3	0.8	0.6*
Dibenz(a,h)anthracene	+						1.3*	1.3*	1.3*
Indeno(1,2,3-cd)pyrene	0.5	0.5	0.5	0.5	0.5	0.4	0.6	0.6	0.5

*Detection limit.

+No data indicate unsufficient quantitative information to calculate half-life.

TABLE A-26. CONTINUED

	PAH (mg/kg soil)								
	Load Rate (% waste wet/soil dry)								
	0.4%			0.7%			1.0%		
	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
Naphthalene	2.0	2.5	125	2.5	4.0	16	6.0	4.6	76
Fluorene	4.0	2.6	7	7.5	5.9	8	100	2.5	24
Phenanthrene	150	1.3	9	270	1.4	5	350	7.0	20
Anthracene	1.4	1.4	104	4.7	3.3	69	5.3	4.6	9
Fluoranthene	130	9.6	7	250	2.1	8	340	1.1	24
Pyrene	100	7.4	7	200	2.0	10	270	6.4	24
Benzo(a)anthracene	9.7	1.2	12	2.3	3.1	14	3.3	8.3	25
Chrysene	1.3	1.0	8	2.8	2.1	8	3.9	1.1	28
Benzo(b)fluoranthene	5.7	1.2	20	1.1	1.0	9	1.5	3.5	23
Benzo(k)fluoranthene	5.7	0.6	10	9.0	1.7	19	1.3	4.5	35
Benzo(a)pyrene	1.1	0	0	1.2	1.5	12	1.6	3.0	19
Benzo(ghi)perylene	9.2	5.9	64	5.6	0	0	8.9	3.8	43
Dibenz(a,h)anthracene	1.3	0	0	1.3	0	0	1.3	0	0
Indeno(1,2,3-cd)pyrene	5.0	0	0	4.7	0.6	12	5.7	0.6	10

TABLE A-27. RESULTS FOR PAH ANALYSIS AT LOW SOIL MOISTURE CONTENT FOR CREOSOTE WASTE MIXED WITH KIDMAN SANDY LOAM SOIL AFTER 158 DAYS INCUBATION TIME

PAH (mg/kg soil)	Load Rate (% waste wet/soil dry)		
	0.4%	0.7%	1.0%
Naphthalene	46.4	0.30*	270
Fluorene	0.2*	4.8	92.3
Phenanthrene	+	22.0	500
Anthracene	0.2*	2.9	
Fluoranthene		21.4	
Pyrene		19.7	
Benz(a)anthracene	0.8*	0.8*	73.7
Chrysene		2.9	47.1
Benzo(b)fluoranthene		1.1	35.6
Benzo(k)fluoranthene	0.2*	0.2*	10.4
Benzo(a)pyrene	0.2*	0.2*	6.3
Benzo(ghi)perylene	0.6*	0.6*	0.6*
Dibenz(a,h)anthracene			1.3*
Indeno(1,2,3)pyrene	0.3*	0.3*	0.3*

*Detection limit.

+No data indicate insufficient quantitative information to calculate half-life.

TABLE A-28. RESULTS FOR PAH ANALYSIS AT LOW SOIL MOISTURE CONTENT FOR PCP WASTE MIXED WITH DURANT CLAY LOAM SOIL IMMEDIATELY AFTER WASTE ADDITION

	PAH (mg/kg soil)	
	Load Rate (% waste wet/soil dry)	
	0.3%	0.7%
Naphthalene	29.1	260
Fluorene	42.7	110
Phenanthrene	120	340
Anthracene	10.0	90.1
Fluoranthene	110	35.4
Pyrene	100	350
Benz(a)anthracene	0.2*	65.4
Chrysene	0.2*	38.1
Benzo(b)fluoranthene	10.5	53.0
Benzo(k)fluoranthene	0.2*	14.6
Benzo(a)pyrene	0.2*	18.2
Benzo(ghi)perylene	0.6*	0.6*
Dibenz(a,h)anthracene	1.3*	1.3*
Indeno(1,2,3)pyrene	0.3*	12.2

*Detection limit.

TABLE A-29. RESULTS FOR PAH ANALYSIS AT LOW SOIL MOISTURE CONTENT FOR PCP WASTE MIXED WITH DURANT CLAY LOAM SOIL AFTER 140 DAYS INCUBATION TIME

	PAH (mg/kg soil)	
	Load Rate (% waste wet/soil dry)	
	0.3%	0.7%
Naphthalene	71.9	280
Fluorene	0.2*	44.6
Phenanthrene	29.0	250
Anthracene	0.2*	77.2
Fluoranthene	45.6	250
Pyrene	42.2	270
Benz(a)anthracene	34.1	54.8
Chrysene	7.1	30.0
Benzo(b)fluoranthene	12.4	37.0
Benzo(k)fluoranthene	0.2*	12.1
Benzo(a)pyrene	0.2*	8.8
Benzo(ghi)perylene	0.6*	0.6*
Dibenz(a,h)anthracene	1.3*	1.3*
Indeno(1,2,3)pyrene	0.3*	0.3*

*Detection limit.

TABLE A-30. RESULTS FOR PAH ANALYSIS AT LOW SOIL MOISTURE CONTENT FOR PCP WASTE MIXED WITH KIDMAN SANDY LOAM SOIL IMMEDIATELY AFTER WASTE ADDITION

PAH (mg/kg soil)	Load Rate (% waste wet/soil dry)	
	0.075%	0.3%
Naphthalene	34.7	96.7
Fluorene	0.2*	20.4
Phenanthrene	30.8	99.3
Anthracene	0.2*	0.2*
Fluoranthene	27.4	91.0
Pyrene	28.0	95.7
Benz(a)anthracene	0.8*	38.2
Chrysene	ND+	9.9
Benzo(b)fluoranthene	0.2*	0.2*
Benzo(k)fluoranthene	0.2*	0.2*
Benzo(a)pyrene	0.2*	0.2*
Benzo(ghi)perylene	0.6*	0.6*
Dibenz(a,h)anthracene	1.3*	1.3*
Indeno(1,2,3)pyrene	0.3*	0.3*

*Detection limit.
+ND = Not detected (peak not present).

TABLE A-31. RESULTS FOR PAH ANALYSIS AT LOW SOIL MOISTURE CONTENT FOR PCP WASTE MIXED WITH KIDMAN SANDY LOAM SOIL AFTER 140 DAYS INCUBATION TIME

	PAH (mg/kg soil)	
	Load Rate (% waste wet/soil dry)	
	0.075%	0.3%
Naphthalene	0.30*	82.0
Fluorene	0.2*	0.2*
Phenanthrene	4.7	50.0
Anthracene	0.2*	0.2*
Fluoranthene	16.6	55.7
Pyrene	0.2*	48.0
Benz(a)anthracene	0.8*	35.2
Chrysene	3.4	6.9
Benzo(b)fluoranthene	0.2*	0.2*
Benzo(k)fluoranthene	0.2*	0.2*
Benzo(a)pyrene	0.2*	0.2*
Benzo(ghi)perylene	0.6*	0.6*
Dibenz(a,h)anthracene	1.3*	1.3*
Ideno(1,2,3)pyrene	0.3*	0.3*

*Detection limit.

TABLE A-32. RESULTS FOR PAH ANALYSIS AT -1 BAR SOIL MOISTURE CONTENT FOR API SEPARATOR SLUDGE REAPPLIED TO DURANT CLAY LOAM SOIL (IMMEDIATELY AFTER WASTE ADDITION)

	PAH (mg/kg soil)					
	Loading Rate					
	M/M*			H/NR+		
	Replicate Reactors					
	1	2	3	1	2	3
Naphthalene	33.6	28.9	47.7	ND#	ND	ND
Fluorene	17.3	6.8	25.5	14.3	29.4	15.2
Phenanthrene	120	88.7	120	54.3	39.8	49.2
Anthracene	17.7	10.4	20.2	ND	ND	ND
Fluoranthene	ND	720	920	590	420	520
Pyrene	ND	ND	ND	610	470	550
Benzo(a)anthracene	92.6	180	280	130	86.6	200
Chrysene	ND	ND	ND	72.3	43.7	ND
Benzo(b)fluoranthene	110	54.5	150	ND	ND	ND
Benzo(k)fluoranthene	380	63.9	650	ND	ND	ND
Benzo(a)pyrene	ND	34.6	ND	ND	ND	ND
Benzo(ghi)perylene	ND	ND	ND	ND	ND	ND
Dibenz(a,h)anthracene	ND	ND	ND	ND	ND	ND
Indeno(1,2,3-cd)pyrene	ND	ND	ND	ND	ND	ND

*M/M = originally loaded at medium rate (9%), reloaded at medium rate.
+H/NR = originally loaded at high rate (12%), not reloaded.
#ND = not detected (peak not present).

TABLE A-32. CONTINUED

	PAH (mg/kg soil)					
	M/M			H/NR		
	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
Naphthalene	36.7	9.8	27	-	-	-
Fluorene	16.5	9.4	57	19.6	8.5	43
Phenanthrene	110	18.1	16	47.7	7.4	15
Anthracene	16.1	5.1	31	-	-	-
Fluoranthene	547	484	89	510	85.5	17
Pyrene	-	-	-	543	70.2	13
Benzo(a)anthracene	184	940	51	139	57.2	41
Chrysene	-	-	-	38.7	36.4	94
Benzo(b)fluoranthene	105	48.0	46	-	-	-
Benzo(d)fluoranthene	365	243	81	-	-	-
Benzo(a)pyrene	11.5	20.0	173	-	-	-
Benzo(ghi)perylene	-	-	-	-	-	-
Dibenz(a,h)anthracene	-	-	-	-	-	-
Indeno(1,2,3-cd)pyrene	-	-	-	-	-	-

TABLE A-33. RESULTS FOR PAH ANALYSIS AT -1 BAR SOIL MOISTURE CONTENT FOR API SEPARATOR SLUDGE REAPPLIED TO DURANT CLAY LOAM SOIL (37 DAYS INCUBATION)

	PAH (mg/kg soil)		
	Loading Rate		
	M/M*		
	Replicate Reactors		
	1	2	3
Naphthalene	5.2	2.4	ND+
Fluorene	7.4	31.1	10.5
Phenanthrene	80.1	130	97.8
Anthracene	8.9	22.0	14.9
Fluoranthene	750	1200	1000
Pyrene	960	170	1200
Benzo(a)anthracene	150	140	210
Chrysene	170	200	130
Benzo(b)fluoranthene	80.0	25.4	260
Benzo(k)fluoranthene	ND	110	ND
Benzo(a)pyrene	100	180	400
Benzo(ghi)perylene	ND	ND	ND
Dibenz(a,h)anthracene	ND	ND	ND
Indeno(1,2,3-cd)pyrene	ND	ND	ND

*M/M = originally loaded at medium rate (9%), reloaded at medium rate.
+ND = not detected (peak not present).

TABLE A-33. CONTINUED

	PAH (mg/kg soil) M/M		
	$\bar{X}$	SD	CV
Naphthalene	2.5	2.6	104
Fluorene	16.3	12.9	79
Phenanthrene	108	25.3	25
Anthracene	15.3	6.6	43
Fluoranthene	983	225	23
Pyrene	1290	378	29
Benzo(a)anthracene	167	37.9	23
Chrysene	167	35.1	21
Benzo(b)fluoranthene	122	122	100
Benzo(k)fluoranthene	36.7	63.5	173
Benzo(a)pyrene	226	155	69
Benzo(ghi)perylene	-	-	-
Dibenz(a,h)anthracene	-	-	-
Indeno(1,2,3-cd)pyrene	-	-	-

TABLE A-34. RESULTS FOR PAH ANALYSIS AT -1 BAR SOIL MOISTURE CONTENT FOR API SEPARATOR SLUDGE REAPPLIED TO DURANT CLAY LOAM SOIL (74 DAYS INCUBATION)

	PAH (mg/kg soil)					
	Loading Rate					
	M/M*			H/NR+		
	Replicate Reactors					
	1	2	3	1	2	3
Naphthalene	ND#	ND	ND	ND	ND	ND
Fluorene	4.7	5.6	8.3	1.2	3.8	1.6
Phenanthrene	52.0	64.0	94.7	21.7	56.6	26.0
Anthracene	ND	ND	20.3	2.9	11.0	3.3
Fluoranthene	610	760	1600	450	850	460
Pyrene	690	870	160	490	940	510
Benzo(a)anthracene	160	210	330	120	220	120
Chrysene	67.7	88.6	150	49.1	96.5	49.3
Benzo(b)fluoranthene	ND	ND	ND	ND	ND	ND
Benzo(k)fluoranthene	64.1	110	190	33.3	110.0	31.6
Benzo(a)pyrene	26.9	48.3	85.6	12.5	49.3	13.4
Benzo(ghi)perylene	ND	ND	ND	ND	ND	ND
Dibenz(a,h)anthracene	ND	ND	ND	12.8	ND	14.9
Indeno(1,2,3-cd)pyrene	ND	ND	ND	ND	ND	ND

*M/M = originally loaded at medium rate (9%), reloaded at medium rate.
+H/NR = originally loaded at high rate (12%), not reloaded.
#ND = not detected (peak not present).

TABLE A-34. CONTINUED

	PAH (mg/kg soil)					
	M/M			H/NR		
	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
Naphthalene	-	-	-	-	-	-
Fluorene	6.2	1.9	30	2.2	1.4	64
Phenanthrene	70.7	22.0	31	34.8	19.0	55
Anthracene	6.8	11.7	173	5.7	4.6	80
Fluoranthene	990	533	54	587	228	39
Pyrene	573	369	64	647	254	39
Benzo(a)anthracene	223	87.3	37	153	57.7	38
Chrysene	102	42.8	41	65	27.3	42
Benzo(b)fluoranthene	-	-	-	-	-	-
Benzo(d)fluoranthene	121	63.7	52	58.3	44.8	77
Benzo(a)pyrene	53.6	29.7	55	25.0	21	84
Benzo(ghi)perylene	-	-	-	-	-	-
Dibenz(a,h)anthracene	-	-	-	9.2	8.1	87
Indeno(1,2,3-cd)pyrene	-	-	-	-	-	-

TABLE A-35. RESULTS FOR PAH ANALYSIS AT -1 BAR SOIL MOISTURE CONTENT FOR API SEPARATOR SLUDGE REAPPLIED TO DURANT CLAY LOAM SOIL (102 DAYS INCUBATION)

	PAH (mg/kg soil)		
	Loading Rate		
	M/M[*]		
	Replicate Reactors		
	1	2	3
Naphthalene	ND[+]	ND	-[#]
Fluorene	2.0	2.8	-
Phenanthrene	14.5	21.3	-
Anthracene	5.4	6.4	-
Fluoranthene	550	630	-
Pyrene	550	650	-
Benzo(a)anthracene	190	200	-
Chrysene	68.7	71.8	-
Benzo(b)fluoranthene	86.0	85.0	-
Benzo(k)fluoranthene	48.1	110	-
Benzo(a)pyrene	55.8	57.6	-
Benzo(ghi)perylene	ND	0.6[**]	-
Dibenz(a,h)anthracene	490	480	-
Indeno(1,2,3-cd)pyrene	ND	0.3[**]	-

[*] M/M = originally loaded at medium rate (9%), reloaded at medium rate.

[+] ND = not detected (peak not present).

[#] - = sample not analyzed.

[**] Detection limit.

TABLE A-35. CONTINUED

	PAH (mg/kg soil) M/M		
	$\bar{x}$	SD	CV
Naphthalene	-	-	-
Fluorene	2.4	0.6	24
Phenanthrene	17.9	4.8	27
Anthracene	5.9	0.7	12
Fluoranthene	590	56.6	10
Pyrene	600	70.7	12
Benzo(a)anthracene	195	7.1	4
Chrysene	70.3	2.2	3
Benzo(b)fluoranthene	85.5	0.7	1
Benzo(k)fluoranthene	79.1	43.8	55
Benzo(a)pyrene	56.7	1.3	2
Benzo(ghi)perylene	0.3	0.4	141
Dibenz(a,h)anthracene	485	7.1	1
Indeno(1,2,3-cd)pyrene	0.15	0.2	141

TABLE A-36. RESULTS FOR PAH ANALYSIS AT -1/3 BAR SOIL MOISTURE CONTENT FOR API SEPARATOR SLUDGE REAPPLIED TO KIDMAN SANDY LOAM SOIL (IMMEDIATELY AFTER WASTE ADDITION)

	PAH (mg/kg soil)											
	Loading Rate											
	M/M*			L/H+			N/H#			H/NR**		
	Replicate Reactors											
	1	2	3	1	2	3	1	2	3	1	2	3
Naphthalene	31.8	31.3	27.2	69.6	-++	61.8	72.1	68.7	65.8	7.0	61.8	7.0
Fluorene	24.5	10.3	9.4	38.1	-	25.4	21.2	24.1	17.5	4.1	3.6	4.1
Phenanthrene	130	120	110	220	-	160	160	150	140	73.1	67.6	76.3
Anthracene	19.3	13.9	12.9	43.0	-	25.8	21.1	20.8	16.7	6.0	4.5	6.6
Fluoranthene	830	770	740	1600	-	1100	910	860	800	500	460	520
Pyrene	1100	1000	950	1700	-	1300	1200	1100	1000	600	560	640
Benzo(a)anthracene	100	81.7	82.8	540	-	220	100	110	90.1	100	93.6	110
Chrysene	190	150	150	180	-	100	180	180	160	ND##	ND	ND
Benzo(b)flouranthene	ND	ND	ND	ND	-	ND	ND	ND	ND	80.6	73.0	81.7
Benzo(k)flouranthene	180	90.1	84.8	ND	-	75.6	ND	ND	ND	37.9	34.3	38.9
Benzo(a)pyrene	160	70.9	72.0	180	-	130	80.5	130	73.2	62.1	55.3	61.6
Benzo(ghi)perylene	ND	ND	ND	ND	-	ND	ND	ND	ND	ND	ND	ND
Dibenz(a,h)anthracene	ND	ND	ND	ND	-	310	ND	ND	ND	ND	ND	ND
Indeno(1,2,3-cd)pyrene	ND	ND	ND	ND	-	ND	ND	84.0	3.4	0.5	4.0	0.29

*M/M = originally loaded at medium rate (9%), reloaded at medium rate.
+L/H = originally loaded at low rate (6%), reloaded at high rate (12%).
#N/H = nonacclimated soil loaded at high rate (12%).
**N/NR = originally loaded at high rate (12%), not reloaded.
++- = not analyzed.
##ND = not detected (peak not present).

TABLE A-36. CONTINUED

	PAH (mg/kg soil)											
	M/M			L/H			N/H			H/NR		
	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
Naphthalene	30.1	25	8	65.7	5.5	8	68.9	3.2	5	25.3	31.6	125
Fluorene	14.7	8.5	6	31.8	9.0	28	20.9	3.3	16	3.9	0.3	7
Phenanthrene	120	10.0	8	190	42.4	22	150	10	7	72.3	4.4	6
Anthracene	15.3	3.4	22	34.4	12.2	35	19.5	2.5	13	5.7	1.1	19
Fluoranthene	780	45.8	6	1350	353	26	857	55.1	6	493	30.6	6
Pyrene	1000	76.4	8	1500	283	19	1100	100	9	600	40	7
Benzo(a)anthracene	88.2	10.3	12	380	226	60	100	10.0	10	101	8.3	8
Chrysene	163	23.1	14	140	56.6	40	173	11.6	7	-	-	-
Benzo(b)fluoranthene	-	-	-	-	-	-	-	-	-	78.4	4.7	6
Benzo(d)fluoranthene	118	53.5	45	37.8	53.5	141	-	-	-	37.0	2.4	7
Benzo(a)pyrene	101	51.1	51	155	35.4	23	94.6	30.9	33	59.7	3.8	6
Benzo(ghi)perylene	-	-	-	-	-	-	-	-	-	-	-	-
Dibenz(a,h)anthracene	-	-	-	155	219	141	-	-	-	-	-	-
Indeno(1,2,3-cd)pyrene	-	-	-	-	-	-	29.1	47.6	163	1.6	2.1	131

TABLE A-37. RESULTS FOR PAH ANALYSIS AT -1/3 BAR SOIL MOISTURE CONTENT FOR API SEPARATOR SLUDGE REAPPLIED TO KIDMAN SANDY LOAM SOIL (37 DAYS INCUBATION)

	PAH (mg/kg soil)								
	Loading Rate								
	M/M*			L/H+			N/H#		
	Replicate Reactors								
	1	2	3	1	2	3	1	2	3
Naphthalene	15.5	14.7	15.3	27.4	33.0	-**	12.9	10.8	9.4
Fluorene	10.5	11.4	14.3	24.1	29.4	-	20.0	17.3	16.2
Phenanthrene	30.0	100	100	180	200	-	140	140	130
Anthracene	16.0	16.8	17.7	33.3	39.7	-	25.6	23.3	21.9
Fluoranthene	860	890	860	1600	2200	-	950	920	840
Pyrene	1100	1100	1100	2000	2500	-	1200	1100	1100
Benzo(a)anthracene	180	190	180	270	300	-	190	180	170
Chrysene	110	120	120	160	390	-	110	100	100
Benzo(b)flouranthene	ND++	240	ND	0.2##	0.2##	-	240	230	220
Benzo(k)flouranthene	ND	62.5	ND	89.4	ND	-	ND	ND	ND
Benzo(a)pyrene	120	78.5	140	110	210	-	130	130	120
Benzo(ghi)perylene	ND	ND	ND	ND	ND	-	ND	ND	ND
Dibenz(a,h)anthracene	ND	ND	ND	ND	ND	-	ND	ND	ND
Indeno(1,2,3-cd)pyrene	ND	ND	ND	ND	ND	-	ND	ND	ND

*M/M = originally loaded at medium rate (9%), reloaded at medium rate.
+L/H = originally loaded at low rate (6%), reloaded at high rate (12%).
#N/H = nonacclimated soil loaded at high rate (12%).
**- = not analyzed.
++ND = not detected (peak not present).
##Detection limit.

TABLE A-37. CONTINUED

	PAH (mg/kg soil)								
	M/M			L/H			N/H		
	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
Naphthalene	15.2	0.4	3	30.2	4.0	13	11.0	1.8	16
Fluorene	12.1	2.0	16	26.8	3.8	14	17.8	2.0	11
Phenanthrene	76.7	40.4	53	190	14.1	7	136	5.8	4
Anthracene	16.8	0.9	5	36.5	4.5	12	23.6	1.9	8
Fluoranthene	870	17.3	2	1900	424	22	403	36.9	6
Pyrene	1100	0	0	2250	354	16	1100	57.7	5
Benzo(a)anthracene	183	5.8	3	285	29.2	7	180	10	6
Chrysene	117	5.8	5	275	162	59	103	5.8	6
Benzo(b)fluoranthene	80	138	173	0.2	0	0	230	10	4
Benzo(k)fluoranthene	20.8	36.1	173	44.7	63.2	141	43.3	75.1	173
Benzo(a)pyrene	113	31.4	28	160	70.7	44	83.3	72.3	87
Benzo(ghi)perylene	-	-	-	-	-	-	-	-	-
Dibenz(a,h)anthracene	-	-	-	-	-	-	-	-	-
Indeno(a,2,3-cd)pyrene	-	-	-	-	-	-	7.5	13.0	173

TABLE A-38. RESULTS FOR PAH ANALYSIS AT -1/3 BAR SOIL MOISTURE CONTENT FOR API SEPARATOR SLUDGE REAPPLIED TO KIDMAN SANDY LOAM SOIL (74 DAYS INCUBATION)

	PAH (mg/kg soil)											
	Loading Rate											
	M/M*			L/H+			N/H#			H/NR**		
	Replicate Reactors											
	1	2	3	1	2	3	1	2	3	1	2	3
Naphthalene	ND++	ND	ND	12.0	10.3	13.7	ND	ND	4.9	ND	ND	ND
Fluorene	11.1	10.7	30.2	28.1	24.4	16.6	15.8	11.8	17.1	4.9	5.0	7.8
Phenanthrene	85.2	82.0	220	190	160	170	130	110	120	67.8	61.8	77.3
Anthracene	10.1	10.2	330	ND	ND	0.2##	ND	ND	ND	ND	ND	ND
Fluoranthene	830	790	780	3300	2700	1400	1200	1000	0.2##	740	680	870
Pyrene	840	800	ND	420	2200	1300	1100	890	1000	680	630	830
Benzo(a)anthracene	180	180	580	400	330	280	220	180	210	130	140	180
Chrysene	80.1	76.8	220	160	140	84.0	91.0	75.7	91.2	57.0	62.8	79.8
Benzo(b)flouranthene	ND	ND	ND	ND	ND	120	95.1	78.8	91.9	ND	ND	ND
Benzo(k)flouranthene	50.8	49.8	180	110	200	120	130	96.7	130	45.0	84.5	100
Benzo(a)pyrene	52.8	57.4	170	100	92.0	34.4	55.4	42.8	53.9	18.8	33.0	44.3
Benzo(ghi)perylene	ND	ND	0.6##	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dibenz(a,h)anthracene	ND	ND	ND	810	ND	ND	470	270	440	ND	240	300
Indeno(1,2,3-cd)pyrene	ND	ND	ND	ND	0.29	11.7	ND	ND	ND	ND	ND	ND

*M/M = originally loaded at medium rate (9%), reloaded at medium rate.
+L/H = originally loaded at low rate (6%), reloaded at high rate (12%).
#N/H = nonacclimated soil loaded at high rate (12%).
**N/NR = originally loaded at high rate (12%), not reloaded.
++ND = not detected (peak not present).
##Detection limit.

TABLE A-38. CONTINUED

	PAH (mg/kg soil)											
	M/M			L/H			N/H			H/NR		
	x̄	SD	CV	x̄	SD	CV	x̄	SD	CV	x̄	SD	CV
Naphthalene	-	-	-	12	1.7	14	1.6	2.8	175	-	-	-
Fluorene	17.3	11.1	64	23.0	5.9	25	14.9	2.8	19	5.9	1.7	28
Phenanthrene	129	78.8	61	173	15.3	9	120	10	8	69.0	7.8	11
Anthracene	117	185	158	0.2	0	0	-	-	-	0.2	0	0
Fluoranthene	800	26.5	3	2460	971	39	733	643	88	763	97.1	13
Pyrene	547	474	87	1300	890	68	997	105	11	713	104	15
Benzo(a)anthracene	313	231	74	337	60.3	18	203	20.8	10	150	26.5	18
Chrysene	126	81.7	65	128	39.4	31	86.0	8.9	10	66.5	11.9	18
Benzo(b)fluoranthene	-	-	-	40	69.3	173	88.6	8.6	10	-	-	-
Benzo(d)fluoranthene	93.5	74.9	80	143	49.3	34	118.9	19.2	16	76.5	28.4	37
Benzo(a)pyrene	93.4	66.4	71	75.5	35.8	47	50.7	6.9	14	32.0	12.8	40
Benzo(ghi)perylene	0.2	0.3	173	-	-	-	-	-	-	-	-	-
Dibenz(a,h)anthracene	-	-	-	270	468	173	393	108	27	180	159	88
Indeno(1,2,3-cd)pyrene	273	249	91	399	6.7	167	-	-	-	-	-	-

TABLE A-39. RESULTS FOR PAH ANALYSIS AT -1/3 BAR SOIL MOISTURE CONTENT FOR API SEPARATOR SLUDGE REAPPLIED TO KIDMAN SANDY LOAM SOIL (102 DAYS INCUBATION)

	PAH (mg/kg soil)								
	Loading Rate								
	M/M*			L/H+			N/H#		
	Replicate Reactors								
	1	2	3	1	2	3	1	2	3
Naphthalene	ND**	ND	ND	0.3++	3.2	4.4	2.0	0.6	ND
Fluorene	ND	ND	0.6++	26.4	26.9	23.2	29.3	15.1	19.2
Phenanthrene	1.1	ND	7.2	170	180	170	230	110	130
Anthracene	0.2++	ND	ND	19.6	20.7	ND	7.8	3.0	ND
Fluoranthene	0.9	ND	53.8	2400	2700	1500	3000	1000	1500
Pyrene	0.8	0.17++	66.2	2200	380	1700	3500	1100	1300
Benzo(a)anthracene	ND	ND	8.0	350	130	550	430	210	410
Chrysene	ND	ND	4.4	130	130	ND	140	75.0	200
Benzo(b)flouranthene	ND	ND	ND	150	160	ND	170	95.8	ND
Benzo(k)flouranthene	ND	ND	ND	92.9	94.0	ND	100	54.3	ND
Benzo(a)pyrene	ND	ND	0.5	97.4	110	ND	120	63.3	19.7
Benzo(ghi)perylene	ND	ND	ND	490	ND	ND	ND	ND	ND
Dibenz(a,h)anthracene	ND	ND	ND	1200	1400	ND	290	720	ND
Indeno(1,2,3-cd)pyrene	ND	ND	ND	0.29++	0.29++	ND	410	ND	ND

*M/M = originally loaded at medium rate (9%), reloaded at medium rate.
+L/H = originally loaded at low rate (6%), reloaded at high rate (12%).
#N/H = nonacclimated soil loaded at high rate (12%).
**ND = not detected (peak not present).
++Detection limit.

TABLE A-39. CONTINUED

	PAH (mg/kg soil)								
	M/M			L/H			N/H		
	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
Naphthalene	-	-	-	2.6	2.1	81	0.9	1.0	118
Fluorene	0.2	4	173	255	20	78	21.2	7.3	34
Phenanthrene	2.8	3.9	140	173	5.8	3	156.7	64.3	41
Anthracene	0.1	0	-	13.4	11.7	87	3.6	3.9	109
Fluoranthene	18.2	30.8	169	2200	625	28	1833	1040	57
Pyrene	22.4	37.9	169	1427	940	66	1967	1330	68
Benzo(a)anthracene	2.7	4.6	173	343	210	61	350	122	35
Chrysene	1.5	2.5	173	86.7	75.1	87	138	72/5	45
Benzo(b)fluoranthene	-	-	-	103	89.6	87	88.6	85.2	96
Benzo(k)fluoranthene	-	-	-	62.3	53.9	87	51.4	50.1	97
Benzo(a)pyrene	2	29	173	69.1	60.2	87	67.7	50.3	74
Benzo(ghi)perylene	-	-	-	163	283	173	-	-	-
Dibenz(a,h)anthracene	-	-	-	867	757	87	337	362	108
Indeno(a,2,3-cd)pyrene	-	-	-	0.3	0	0	137	237	173

TABLE A-40. RESULTS FOR PAH ANALYSIS AT -1 BAR SOIL MOISTURE CONTENT FOR SLOP OIL EMULSION SOLIDS REAPPLIED TO DURANT CLAY LOAM SOIL (IMMEDIATELY AFTER WASTE ADDITION)

	PAH (mg/kg soil)					
	Loading Rate					
	M/M*			H/NR+		
	Replicate Reactors					
	1	2	3	1	2	3
Naphthalene	240	270	330	40.5	27.7	19.3
Fluorene	93.5	110	120	56.4	44.2	37.4
Phenanthrene	560	710	840	ND#	360	270
Anthracene	92.2	110	130	74.5	58.9	46.7
Fluoranthene	6000	8900	10000	20000	9200	4000
Pyrene	6400	8900	12000	ND	ND	4500
Benzo(a)anthracene	460	550	620	570	470	390
Chrysene	180	220	240	ND	ND	ND
Benzo(b)fluoranthene	ND	ND	ND	150	100	100
Benzo(k)fluoranthene	51.9	59.7	60.9	ND	ND	ND
Benzo(a)pyrene	62.6	72.6	81.4	74.0	45.2	45.2
Benzo(ghi)perylene	ND	ND	ND	ND	ND	ND
Dibenz(a,h)anthracene	ND	ND	ND	ND	ND	ND
Indeno(1,2,3-cd)pyrene	ND	ND	ND	ND	2.0	1.9

*M/M = originally loaded at medium rate (12%), reloaded at medium rate.
+H/NR = originally loaded at high rate (14%), not reloaded.
#ND = not detected (peak not present).

TABLE A-40. CONTINUED

	PAH (mg/kg soil)					
	M/M			H/NR		
	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
Naphthalene	270	30	11	29.2	10.7	37
Fluorene	108	13.4	12	46	9.6	21
Phenanthrene	703	140	20	210	187	89
Anthracene	111	18.9	17	60.0	13.9	23
Fluoranthene	8300	2066	25	11100	8200	74
Pyrene	9100	2805	31	1500	2600	173
Benzo(a)anthracene	543	80.2	15	477	90.2	19
Chrysene	213	30.6	14	-	-	-
Benzo(b)fluoranthene	-	-	-	117	28.9	25
Benzo(k)fluoranthene	57.5	4.9	8	-	-	-
Benzo(a)pyrene	72.2	9.4	13	54.8	16.6	30
Benzo(ghi)perylene	-	-	-	-	-	-
Dibenz(a,h)anthracene	15.5	13.4	87	-	-	-
Indeno(1,2,3-cd)pyrene	-	-	-	1.3	1.1	87

TABLE A-41. RESULTS FOR PAH ANALYSIS AT -1 BAR SOIL MOISTURE CONTENT FOR SLOP OIL EMULSION SOLIDS REAPPLIED TO DURANT CLAY LOAM SOIL (37 DAYS INCUBATION)

	PAH (mg/kg soil)		
	Loading Rate		
	M/M*		
	Replicate Reactors		
	1	2	3
Naphthalene	760	180	190
Fluorene	240	140	150
Phenanthrene	840	1100	ND+
Anthracene	500	160	160
Fluoranthene	800	25000	25000
Pyrene	720	ND	ND
Benzo(a)anthracene	61.3	1200	1200
Chrysene	67.5	ND	ND
Benzo(b)fluoranthene	ND	ND	ND
Benzo(k)fluoranthene	ND	150	46.8
Benzo(a)pyrene	13.9	ND	50.9
Benzo(ghi)perylene	ND	ND	ND
Dibenz(a,h)anthracene	ND	ND	ND
Indeno(1,2,3-cd)pyrene	3.2	1.4	ND

*M/M = originally loaded at medium rate (12%), reloaded at medium rate.
+ND = not detected (peak not present).

TABLE A-41. CONTINUED

	PAH (mg/kg soil) M/M		
	x̄	SD	CV
Naphthalene	377	332	88
Fluorene	177	55.1	31
Phenanthrene	647	575	89
Anthracene	273	196	72
Fluoranthene	17000	14000	83
Pyrene	240	416	173
Benzo(a)anthracene	820	657	80
Chrysene	22.5	39.0	173
Benzo(b)fluoranthene	-	-	-
Benzo(k)fluoranthene	65.6	76.8	117
Benzo(a)pyrene	71.6	70.4	98
Benzo(ghi)perylene	-	-	-
Dibenz(a,h)anthracene	-	-	-
Indeno(1,2,3-cd)pyrene	1.53	1.6	105

TABLE A-42. RESULTS FOR PAH ANALYSIS AT -1 BAR SOIL MOISTURE CONTENT FOR SLOP OIL EMULSION SOLIDS REAPPLIED TO DURANT CLAY LOAM SOIL (74 DAYS INCUBATION)

	PAH (mg/kg soil)					
	Loading Rate					
	M/M*			H/NR+		
	Replicate Reactors					
	1	2	3	1	2	3
Naphthalene	16.0	37.3	24.7	12.4	30.2	6.6
Fluorene	75.9	110	59.9	ND#	85.7	ND
Phenanthrene	480	670	540	10.3	0.2**	10.5
Anthracene	0.2**	0.2**	0.2**	80.3	0.2**	12.5
Fluoranthene	4200	5700	4400	1400	4700	2500
Pyrene	4200	5800	4600	680	4700	870
Benzo(a)anthracene	590	850	600	260	690	370
Chrysene	140	200	130	70.5	160	96.5
Benzo(b)fluoranthene	ND	ND	ND	ND	ND	ND
Benzo(k)fluoranthene	61.0	82.4	5.2	26.9	ND	38.9
Benzo(a)pyrene	18.9	33.2	0.15**	27.3	26.9	37.8
Benzo(ghi)perylene	ND	ND	ND	110	ND	160
Dibenz(a,h)anthracene	ND	ND	ND	43.9	ND	ND
Indeno(1,2,3-cd)pyrene	7.3	16.6	7.5	27.5	13.5	ND

*M/M = originally loaded at medium rate (12%), reloaded at medium rate.
+H/NR = originally loaded at high rate (14%), not reloaded.
#ND = not detected (peak not present).
**Detection limit.

TABLE A-42. CONTINUED

	PAH (mg/kg soil)					
	M/M			H/NR		
	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
Naphthalene	26	10.7	41	16.4	12.3	75
Fluorene	81.9	25.6	31	28.6	49.5	173
Phenanthrene	563	97.1	17	7.0	5.9	84
Anthracene	0.2	0	0	31.0	43.2	139
Fluoranthene	4770	814	17	2900	1680	59
Pyrene	4870	833	17	2080	2270	109
Benzo(a)anthracene	680	147	22	440	223	51
Chrysene	157	37.9	24	109	46.0	42
Benzo(b)fluoranthene	-	-	-	-	-	-
Benzo(k)fluoranthene	49.2	40.0	8	21.9	19.9	91
Benzo(a)pyrene	17.4	16.6	95	30.7	6.2	20
Benzo(ghi)perylene	-	-	-	-	-	-
Dibenz(a,h)anthracene	-	-	-	14.6	2535	173
Indeno(1,2,3-cd)pyrene	10.5	5.3	51	13.7	13.8	101

TABLE A-43. RESULTS FOR PAH ANALYSIS AT -1 BAR SOIL MOISTURE CONTENT FOR SLOP OIL EMULSION SOLIDS REAPPLIED TO DURANT CLAY LOAM SOIL (102 DAYS INCUBATION)

	PAH (mg/kg soil)		
	Loading Rate		
	M/M[*]		
	Replicate Reactors		
	1	2	3
Naphthalene	20.3	ND[+]	ND
Fluorene	25.1	0.6	ND
Phenanthrene	200	2.7	3.9
Anthracene	ND	ND	ND
Fluoranthene	6700	2.3	44.0
Pyrene	4300	7.1	45.0
Benzo(a)anthracene	750	1.5	6.8
Chrysene	ND	ND	ND
Benzo(b)fluoranthene	ND	ND	1.0
Benzo(k)fluoranthene	ND	ND	ND
Benzo(a)pyrene	5.5	0.2[#]	0.2[#]
Benzo(ghi)perylene	ND	ND	ND
Dibenz(a,h)anthracene	ND	ND	ND
Indeno(1,2,3-cd)pyrene	ND	ND	ND

[*] M/M = originally loaded at medium rate (12%), reloaded at medium rate.

[+] ND = not detected (peak not present).

[#] Detection limit.

TABLE A-43. CONTINUED

	PAH (mg/kg soil) M/M		
	$\bar{X}$	SD	CV
Naphthalene	6.8	11.7	173
Fluorene	8.6	14.3	167
Phenanthrene	68.9	114	165
Anthracene	-	-	-
Fluoranthene	2250	3860	171
Pyrene	1451	2470	170
Benzo(a)anthracene	253	431	170
Chrysene	-	-	-
Benzo(b)fluoranthene	0.3	0.6	173
Benzo(k)fluoranthene	-	0	-
Benzo(a)pyrene	1.9	3.1	160
Benzo(ghi)perylene	-	-	-
Dibenz(a,h)anthracene	-	-	-
Indeno(1,2,3-cd)pyrene	-	-	-

TABLE A-44. RESULTS FOR PAH ANALYSIS AT -1/3 BAR SOIL MOISTURE CONTENT FOR SLOP OIL EMULSION SOLIDS REAPPLIED TO KIDMAN SANDY LOAM SOIL (IMMEDIATELY AFTER WASTE ADDITION)

	PAH (mg/kg soil)											
	Loading Rate											
	M/M*			L/H+			N/H#			H/NR**		
	Replicate Reactors											
	1	2	3	1	2	3	1	2	3	1	2	3
Naphthalene	170	160	160	250	270	290	140	150	140	ND++	34.8	78.0
Fluorene	72.7	73.9	73.4	110	120	120	57.3	51.1	50.5	ND	35.0	34.0
Phenanthrene	830	690	700	590	630	630	350	350	330	ND	260	270
Anthracene	91.5	84.8	87.8	100	110	130	58.1	54.5	52.5	ND	43.2	54.7
Fluoranthene	30000	26000	26000	6200	7300	4500	8500	8600	8200	430	3600	2300
Pyrene	ND	ND	ND	6700	7400	5500	ND	ND	ND	530	370	2500
Benzo(a)anthracene	ND	ND	ND	500	520	2100	4200	370	360	87.2	ND	860
Chrysene	ND	ND	ND	290	210	170	ND	ND	ND	ND	ND	ND
Benzo(b)flouranthene	ND	ND	ND	210	220	ND	ND	ND	ND	ND	ND	ND
Benzo(k)flouranthene	ND	ND	ND	140	66.0	ND	ND	ND	ND	ND	ND	ND
Benzo(a)pyrene	51.5	69.2	67.1	ND	58.9	ND	29.5	ND	1.2	ND	47.7	ND
Benzo(ghi)perylene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dibenz(a,h)anthracene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Indeno(1,2,3-cd)pyrene	ND	ND	ND	5.7	5.3	ND	ND	ND	1.6	ND	0.29##	ND

*M/M = originally loaded at medium rate (8%), reloaded at medium rate.
+L/H = originally loaded at low rate (6%), reloaded at high rate (12%).
#N/H = nonacclimated soil loaded at high rate (12%).
**N/NR = originally loaded at high rate (12%), not reloaded.
++ND = not detected (peak not present).
##Detection limit.

TABLE A-44. CONTINUED

	PAH (mg/kg soil)											
	M/M			L/H			N/H			H/NR		
	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
Naphthalene	163	5.8	3	270	20	7	143	5.8	4	37.6	39.1	104
Fluorene	73.3	0.6	1	117	5.8	5	53.0	3.8	7	23	199	87
Phenanthrene	740	78.1	11	617	231	4	343	11.6	3	177	153	87
Anthracene	88.0	3.4	4	173	15.3	13	55.0	2.8	5	32.6	28.8	88
Fluoranthene	27000	2300	8	6000	1410	24	8400	208	2	2110	1600	76
Pyrene	-	-	-	6500	961	15	-	-	-	1130	1190	105
Benzo(a)anthracene	-	-	-	1040	918	88	1640	2200	135	439	391	89
Chrysene	-	-	-	223	61.1	27	-	-	-	-	-	-
Benzo(b)fluoranthene	-	-	-	143	124	87	-	-	-	-	-	-
Benzo(d)fluoranthene	-	-	-	68.7	70.0	102	-	-	-	-	-	-
Benzo(a)pyrene	62.6	9.7	15	19.6	34.0	17	10.2	16.7	163	15.9	27.5	173
Benzo(ghi)perylene	-	-	-	-	-	-	-	-	-	-	-	-
Dibenz(a,h)anthracene	-	-	-	-	-	-	-	-	-	-	-	-
Indeno(1,2,3-cd)pyrene	-	-	-	2.9	4.0	141	0.5	0.9	173	0.1	0.2	170

TABLE A-45. RESULTS FOR PAH ANALYSIS AT -1/3 BAR SOIL MOISTURE CONTENT FOR SLOP OIL EMULSION SOLIDS REAPPLIED TO KIDMAN SANDY LOAM SOIL (37 DAYS INCUBATION)

	PAH (mg/kg soil)								
	Loading Rate								
	M/M*			L/H+			N/H#		
	Replicate Reactors								
	1	2	3	1	2	3	1	2	3
Naphthalene	100	68.7	94.2	87.4	83.7	240	100	86.0	98.2
Fluorene	100	97.6	87.3	67.3	65.2	170	110	68.6	84.6
Phenanthrene	970	590	500	560	560	1500	820	700	480
Anthracene	130	52.4	41.1	73.5	71.5	200	110	82.8	42.1
Fluoranthene	33000	2000	3700	21000	21000	56000	27000	25000	5600
Pyrene	ND**	ND	4500	ND	ND	ND	ND	ND	ND
Benzo(a)anthracene	ND	250	170	510	500	1200	ND	ND	ND
Chrysene	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzo(b)flouranthene	ND	ND	ND	ND	65.9	ND	ND	ND	ND
Benzo(k)flouranthene	ND	ND	ND	90.6	72.2	190	ND	74.9	ND
Benzo(a)pyrene	ND	ND	ND	140	81.2	210	ND	75.3	ND
Benzo(ghi)perylene	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dibenz(a,h)anthracene	ND	ND	ND	ND	ND	ND	ND	9.8	ND
Indeno(1,2,3-cd)pyrene	ND	ND	ND	ND	ND	ND	ND	ND	ND

*M/M = originally loaded at medium rate (8%), reloaded at medium rate.
+L/H = originally loaded at low rate (6%), reloaded at high rate (12%).
#N/H = nonacclimated soil loaded at high rate (12%).
**ND = not detected (peak not present).

TABLE A-45. CONTINUED

	PAH (mg/kg soil)								
	M/M			L/H			N/H		
	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
Naphthalene	87.6	16.7	19	137	89.2	65	94.7	7.6	8
Fluorene	95.0	6.8	7	101	59.9	59	87.7	20.9	24
Phenanthrene	687	249	36	873	543	62	667	172	26
Anthracene	74.5	48.4	65	115	73.6	64	78.3	34.2	44
Fluoranthene	12900	17400	135	33000	20200	62	19200	11800	62
Pyrene	500	2600	173	-	-	-	-	-	-
Benzo(a)anthracene	140	128	91	737	401	54	-	-	-
Chrysene	-	-	-	-	-	-	-	-	-
Benzo(b)fluoranthene	-	-	-	-	-	-	-	-	-
Benzo(k)fluoranthene	-	-	-	116	65.7	57	25.0	43.2	173
Benzo(a)pyrene	-	-	-	141	68.9	49	25.1	43.5	173
Benzo(ghi)perylene	-	-	-	27.1	46.9	173	-	-	-
Dibenz(a,h)anthracene	-	-	-	-	-	-	3.3	5.7	173
Indeno(a,2,3-cd)pyrene	-	-	-	-	-	-	-	-	-

TABLE A-46. RESULTS FOR PAH ANALYSIS AT -1/3 BAR SOIL MOISTURE CONTENT FOR SLOP OIL EMULSION SOLIDS REAPPLIED TO KIDMAN SANDY LOAM SOIL (74 DAYS INCUBATION)

	PAH (mg/kg soil)											
	Loading Rate											
	M/M*			L/H+			N/H#			H/NR**		
	Replicate Reactors											
	1	2	3	1	2	3	1	2	3	1	2	3
Naphthalene	16.4	20.5	22.9	83.9	53.5	70.5	10.2	16.7	30.1	ND++	ND	ND
Fluorene	37.6	35.7	39.2	83.9	64.6	69.3	2.3	26.4	37.4	16.6	20.7	20.7
Phenanthrene	32000	34000	360	550	530	550	2400	2600	350	190	200	200
Anthracene	3.9	4.3	6.1	0.2##	0.2##	0.2##	0.2##	0.2##	ND	0.2##	0.2##	0.2##
Fluoranthene	2400	2400	2500	3700	0.17	3800	1800	1700	2500	1400	1700	1700
Pyrene	2500	2600	2800	4100	4000	4200	1800	1900	2500	1500	1800	1800
Benzo(a)anthracene	340	330	360	580	520	540	230	240	330	210	230	260
Chrysene	79.7	82.1	81.7	130	120	120	56.1	55.4	73.2	47.0	51.0	62.0
Benzo(b)flouranthene	ND	ND	ND	45.9	7.4	12.3	5.9	6.0	7.6	7.9	6.7	29.5
Benzo(k)flouranthene	1.1	3.0	1.4	25.9	2.5	2.2	0.4	ND	ND	ND	ND	ND
Benzo(a)pyrene	0.2##	7.2	9.4	0.6	16.5	20.5	0.2##	ND	0.2##	0.2##	ND	0.2##
Benzo(ghi)perylene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dibenz(a,h)anthracene	16.2	13.7	10.8	23.2	28.8	18.1	ND	3.3	ND	ND	3.9	4.0
Indeno(1,2,3-cd)pyrene	ND	ND	ND	ND	ND	ND	3.4	6.3	2.8	ND	5.9	3.4

*M/M = originally loaded at medium rate (8%), reloaded at medium rate.
+L/H = originally loaded at low rate (6%), reloaded at high rate (12%).
#N/H = nonacclimated soil loaded at high rate (12%).
**N/NR = originally loaded at high rate (12%), not reloaded.
++ND = not detected (peak not present).
##Detection limit.

TABLE A-46. CONTINUED

	PAH (mg/kg soil)											
	M/M			L/H			N/H			H/NR		
	x̄	SD	CV	x̄	SD	CV	x̄	SD	CV	x̄	SD	CV
Naphthalene	19.9	3.3	16	69.3	15.3	22	19	10.1	50	-	-	-
Fluorene	37.5	1.7	4	72.6	10.1	14	22	17.9	80	19.4	2.3	12
Phenanthrene	10900	18273	167	543	1.5	2	1780	1250	69	196	5.8	3
Anthracene	4.7	1.2	24	0.2*	-	-	0.1	0.1	100	0.2*	-	-
Fluoranthene	2433	57.7	2	2500	2165	9	2000	436	20	1600	173	11
Pyrene	2633	152	6	4100	100	2	2066	379	18	1700	173	10
Benzo(a)anthracene	343	15.2	5	546	30.5	6	267	55	21	233	25	11
Chrysene	81.2	1.3	2	123	5.8	5	61.6	10	16	53.4	7.7	15
Benzo(b)fluoranthene	-	-	-	21.8	21	9	6.5	0.9	15	14.7	12.8	87
Benzo(d)fluoranthene	1.8	1	55	10.2	13.6	130	0.1	0.2	173	-	-	-
Benzo(a)pyrene	5.6	4.8	90	12.6	10.6	83	0.1	0.08	87	0.1	0.1	100
Benzo(ghi)perylene	-	-	-	-	-	-	-	-	-	-	-	-
Dibenz(a,h)anthracene	13.5	2.7	20	23.4	5.3	23	1.1	1.9	173	2.6	23	87
Indeno(1,2,3-cd)pyrene	-	-	-	-	-	-	4.2	1.9	45	3.1	3	96

*Detection limit.

TABLE A-47. RESULTS FOR PAH ANALYSIS AT -1/3 BAR SOIL MOISTURE CONTENT FOR SLOP OIL EMULSION SOLIDS REAPPLIED TO KIDMAN SANDY LOAM SOIL (102 DAYS INCUBATION)

	PAH (mg/kg soil)								
	Loading Rate								
	M/M*			L/H+			N/H#		
	Replicate Reactors								
	1	2	3	1	2	3	1	2	3
Naphthalene	43.0	ND**	ND	60.6	50.7	-++	14.3	37.3	ND
Fluorene	36.9	35.6	35.1	51.9	50.6	-	19.4	34.4	0.3
Phenanthrene	320	320	320	440	410	-	270	410	4.0
Anthracene	ND	0.2##	0.2##	0.2##	ND	-	ND	ND	0.2##
Fluoranthene	3100	2700	2800	3400	3200	-	1800	2800	21.0
Pyrene	3200	3100	3100	4200	3800	-	2200	3400	24.0
Benzo(a)anthracene	5300	520	520	6700	620	-	620	540	2.3
Chrysene	ND	ND	ND	ND	ND	-	ND	ND	ND
Benzo(b)flouranthene	ND	ND	ND	ND	ND	-	ND	ND	ND
Benzo(k)flouranthene	ND	ND	ND	ND	ND	-	ND	ND	ND
Benzo(a)pyrene	8.5	4.5	ND	ND	ND	-	3.1	6.2	ND
Benzo(ghi)perylene	ND	ND	ND	ND	ND	-	ND	ND	ND
Dibenz(a,h)anthracene	ND	ND	ND	ND	ND	-	ND	ND	ND
Indeno(1,2,3-cd)pyrene	ND	ND	ND	ND	ND	-	ND	ND	ND

*M/M = originally loaded at medium rate (8%), reloaded at medium rate.
+L/H = originally loaded at low rate (6%), reloaded at high rate (12%).
#N/H = nonacclimated soil loaded at high rate (12%).
**ND = not detected (peak not present).
++- = not analyzed.
##Detection limit.

TABLE A-47. CONTINUED

	PAH (mg/kg soil)								
	M/M			L/H			N/H		
	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
Naphthalene	14.3	24.8	173	55.6	7	13	19.2	18.8	109
Fluorene	35.9	0.9	3	51.3	0.9	2	18	17	95
Phenanthrene	320	-	-	425	21.2	5	228	206	90
Anthracene	0.1	0.1	100	0.1	0.1	100	0.1	0.1	100
Fluoranthene	287	208	7	3300	141	4	1540	1410	91
Pyrene	3130	57.7	2	4000	283	7	1870	1711	91
Benzo(a)anthracene	523	5.8	1	3660	4299	117	381	329	86
Chrysene	-	-	-	-	-	-	-	-	-
Benzo(b)fluoranthene	-	-	-	-	-	-	-	-	-
Benzo(k)fluoranthene	-	-	-	-	-	-	-	-	-
Benzo(a)pyrene	4.3	4.2	98	-	-	-	-	3.1	100
Benzo(ghi)perylene	-	-	-	-	-	-	-	-	-
Dibenz(a,h)anthracene	-	-	-	-	-	-	-	-	-
Indeno(a,2,3-cd)pyrene	-	-	-	-	-	-	-	-	-

TABLE A-48. RESULTS FOR PAH ANALYSIS AT -1 BAR SOIL MOISTURE CONTENT FOR CREOSOTE WOOD PRESERVING WASTE REAPPLIED TO DURANT CLAY LOAM SOIL (IMMEDIATELY AFTER WASTE ADDITION)

	PAH (mg/kg soil)					
	Loading Rate					
	M/M*			H/NR+		
	Replicate Reactors					
	1	2	3	1	2	3
Naphthalene	230	210	180	340	240	310
Fluorene	7.1	69.7	55.1	49.1	43.6	43.6
Phenanthrene	510	440	280	110	110	120
Anthracene	110	84.2	60.7	110	180	150
Fluoranthene	340	320	250	430	360	440
Pyrene	340	310	250	0.2#	290	360
Benzo(a)anthracene	32.3	30.9	25.0	45.7	37.0	45.2
Chrysene	30.5	27.9	22.6	44.7	38.0	45.6
Benzo(b)fluoranthene	12.5	11.7	9.7	18.1	15.4	19.0
Benzo(k)fluoranthene	9.1	8.2	6.7	13.0	10.4	13.1
Benzo(a)pyrene	7.6	7.2	5.5	10.7	0.16	11.3
Benzo(ghi)perylene	ND**	ND	ND	ND	ND	ND
Dibenz(a,h)anthracene	1.27	1.27	1.27	1.4	1.3#	1.3
Indeno(1,2,3-cd)pyrene	1.3	1.2	0.9	1.7	1.5	1.8

*M/M = originally loaded at medium rate (1.0%), reloaded at medium rate.
+H/NR = originally loaded at high rate (1.3%), not reloaded.
#Detection limit.
**ND = not detected (peak not present).

TABLE A-48. CONTINUED

	PAH (mg/kg soil)					
	M/M			H/NR		
	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
Naphthalene	207	25.2	12	297	51.3	17
Fluorene	44	37.8	75	3.2	0.1	7
Phenanthrene	410	118	29	113	5.8	5
Anthracene	85	24.7	29	147	3.5	24
Fluoranthene	303	47.2	16	410	43.6	11
Pyrene	300	45.8	15	217	191	88
Benzo(a)anthracene	29.4	3.9	13	42.6	4.9	11
Chrysene	27	4	15	42.8	4.1	10
Benzo(b)fluoranthene	11	1.2	10	17.5	1.9	11
Benzo(k)fluoranthene	7.7	0.9	11	12.1	1.6	13
Benzo(a)pyrene	6.6	1.0	15	7.4	6.3	85
Benzo(ghi)perylene	-	-	-	-	-	-
Dibenz(a,h)anthracene	1.3	-	-	1.3	0.1	5
Indeno(1,2,3-cd)pyrene	1.1	0.2	16	1.7	0.2	9

TABLE A-49. RESULTS FOR PAH ANALYSIS AT -1 BAR SOIL MOISTURE CONTENT FOR CREOSOTE WOOD PRESERVING WASTE REAPPLIED TO DURANT CLAY LOAM SOIL (37 DAYS INCUBATION)

	PAH (mg/kg soil)		
	Loading Rate		
	M/M*		
	Replicate Reactors		
	1	2	3
Naphthalene	420	370	530
Fluorene	51.2	73.9	45.6
Phenanthrene	120	100	86.2
Anthracene	130	240	190
Fluoranthene	540	640	560
Pyrene	540	630	570
Benzo(a)anthracene	54.3	72.9	62.9
Chrysene	65.0	72.4	68.4
Benzo(b)fluoranthene	22.9	26.8	25.2
Benzo(k)fluoranthene	14.4	15.6	15.9
Benzo(a)pyrene	12.3	20.9	14.8
Benzo(ghi)perylene	ND+	ND	ND
Dibenz(a,h)anthracene	2.8	2.6	3.3
Indeno(1,2,3-cd)pyrene	3.2	ND	3.8

*M/M = originally loaded at medium rate (1.0%), reloaded at medium rate.
+ND = not detected (peak not present).

TABLE A-49. CONTINUED

	PAH (mg/kg soil) M/M		
	$\bar{x}$	SD	CV
Naphthalene	395	35.4	9
Fluorene	6.25	16	26
Phenanthrene	110	14.2	13
Anthracene	185	77.8	42
Fluoranthene	590	70.7	12
Pyrene	585	63.6	11
Benzo(a)anthracene	63.6	13.2	21
Chrysene	68.7	5.2	8
Benzo(b)fluoranthene	24.8	2.8	11
Benzo(k)fluoranthene	15	0.8	6
Benzo(a)pyrene	16.6	6	37
Benzo(ghi)perylene	-	-	-
Dibenz(a,h)anthracene	2.7	0.1	5
Indeno(1,2,3-cd)pyrene	1.6	2.3	141

TABLE A-50. RESULTS FOR PAH ANALYSIS AT -1 BAR SOIL MOISTURE CONTENT FOR CREOSOTE WOOD PRESERVING WASTE REAPPLIED TO DURANT CLAY LOAM SOIL (74 DAYS INCUBATION)

	PAH (mg/kg soil)					
	Loading Rate					
	M/M*			H/NR+		
	Replicate Reactors					
	1	2	3	1	2	3
Naphthalene	ND#	ND	ND	ND	ND	ND
Fluorene	29.2	56.1	73.5	91.0	15.8	8.1
Phenanthrene	26.5	83.2	120	140	13.7	6.9
Anthracene	700	150	170	190	58.5	26.9
Fluoranthene	340	570	780	960	260	130
Pyrene	370	580	680	870	190	97.4
Benzo(a)anthracene	53.0	79.7	84.7	100	33.3	17.0
Chrysene	51.4	72.1	77.8	96.4	30.6	16.6
Benzo(b)fluoranthene	17.4	23.5	28.4	35.2	10.2	5.6
Benzo(k)fluoranthene	16.4	28.5	29.4	35.4	7.6	3.8
Benzo(a)pyrene	18.0	31.6	31.6	39.1	6.5	3.2
Benzo(ghi)perylene	ND	50.9	49.1	60.7	1.0	ND
Dibenz(a,h)anthracene	2.5	21.4	18.1	22.4	2.4	1.3**
Indeno(1,2,3-cd)pyrene	2.5	9.1	8.9	11.1	1.6	0.7

*M/M = originally loaded at medium rate (1.0%), reloaded at medium rate.
+H/NR = originally loaded at high rate (1.3%), not reloaded.
#ND = not detected (peak not present).
**Detection limit.

TABLE A-50. CONTINUED

	PAH (mg/kg soil)					
	M/M			H/NR		
	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
Naphthalene	-	-	-	-	-	-
Fluorene	52.9	223	42	38.3	45.8	119
Phenanthrene	76.5	47.1	62	53.5	74.9	140
Anthracene	340	312	92	91.8	86.5	94
Fluoranthene	563	220	39	450	446	99
Pyrene	543	158	29	386	422	109
Benzo(a)anthracene	72.5	17	24	50.1	43.9	28
Chrysene	67.1	13.9	21	47.9	42.6	89
Benzo(b)fluoranthene	23.1	5.5	24	17	15.9	94
Benzo(k)fluoranthene	24.7	7.3	29	15.6	17.3	110
Benzo(a)pyrene	27	7.9	29	16.2	19.8	122
Benzo(ghi)perylene	33.3	28.8	87	20.6	34.8	169
Dibenz(a,h)anthracene	14	10	72	8.69	11.9	137
Indeno(1,2,3-cd)pyrene	6.8	3.8	55	4.5	5.8	129

TABLE A-51. RESULTS FOR PAH ANALYSIS AT -1 BAR SOIL MOISTURE CONTENT FOR CREOSOTE WOOD PRESERVING WASTE REAPPLIED TO DURANT CLAY LOAM SOIL (102 DAYS INCUBATION)

	PAH (mg/kg soil)		
	Loading Rate		
	M/M[*]		
	Replicate Reactors		
	1	2	3
Naphthalene	ND[+]	ND	ND
Fluorene	25.7	31.6	23.5
Phenanthrene	12.7	15.7	10.9
Anthracene	60.5	79.0	54.7
Fluoranthene	340	430	340
Pyrene	220	330	290
Benzo(a)anthracene	55.1	74.2	68.4
Chrysene	71.3	81.1	72.3
Benzo(b)fluoranthene	24.7	27.2	25.2
Benzo(k)fluoranthene	15.4	25.5	22.5
Benzo(a)pyrene	14.3	28.1	25.9
Benzo(ghi)perylene	ND	ND	ND
Dibenz(a,h)anthracene	2.4	3.8	4.2
Indeno(1,2,3-cd)pyrene	2.0	3.4	3.6

[*] M/M = originally loaded at medium rate (1.0%), reloaded at medium rate.

[#] ND = not detected (peak not present).

TABLE A-51. CONTINUED

	PAH (mg/kg soil) M/M		
	$\bar{x}$	SD	CV
Naphthalene	-	-	-
Fluorene	26.9	4.2	16
Phenanthrene	13.1	2.4	20
Anthracene	64.7	12.7	20
Fluoranthene	370	51.9	14
Pyrene	280	55.7	20
Benzo(a)anthracene	65.9	9.8	15
Chrysene	74.9	5.4	7
Benzo(b)fluoranthene	25.7	1.3	5
Benzo(k)fluoranthene	21.1	5.2	25
Benzo(a)pyrene	22.8	7.4	33
Benzo(ghi)perylene	-	-	-
Dibenz(a,h)anthracene	3.5	0.9	27
Indeno(1,2,3-cd)pyrene	3	0.8	29

TABLE A-52. RESULTS FOR PAH ANALYSIS AT -1/3 BAR SOIL MOISTURE CONTENT FOR CREOSOTE WOOD PRESERVING WASTE REAPPLIED TO KIDMAN SANDY LOAM SOIL (IMMEDIATELY AFTER WASTE ADDITION)

	PAH (mg/kg soil)											
	Loading Rate											
	M/M*			L/H+			N/H#			H/NR**		
	Replicate Reactors											
	1	2	3	1	2	3	1	2	3	1	2	3
Naphthalene	350	280	320	290	290	290	260	280	280	ND++	ND	ND
Fluorene	160	130	160	150	150	150	170	170	190	100	100	100
Phenanthrene	780	670	730	740	740	740	820	820	860	1300	750	810
Anthracen	250	180	210	190	200	210	180	180	370	530	260	170
Fluoranthene	650	500	620	560	550	550	560	560	580	480	490	560
Pyrene	630	490	570	550	540	540	570	570	580	500	470	550
Benzo(a)anthracene	58.7	47.0	57.4	51.8	49.5	50.5	52.1	52.1	53.3	37.4	45.4	51.7
Chrysene	56.0	46.6	54.9	50.5	46.4	48.1	49.9	49.9	51.7	46.0	42.4	48.8
Benzo(b)flouranthene	23.0	19.0	21.4	21.5	18.8	19.4	20.5	20.6	21.2	30.3	17.4	19.9
Benzo(k)flouranthene	12.9	14.1	16.6	19.7	13.4	14.4	3.5	3.5	3.7	11.0	9.9	11.6
Benzo(a)pyrene	15.1	12.1	14.0	20.5	11.9	12.0	13.0	13.0	13.7	13.8	10.5	12.3
Benzo(ghi)perylene	ND	ND	ND	ND	ND	ND	0.8	0.8	ND	ND	ND	ND
Dibenz(a,h)anthracene	1.3	1.5	2.3	6.3	1.5	4.8	1.6	1.6	1.8	1.3##	1.3	1.3##
Indeno(1,2,3-cd)pyrene	2.1	2.4	2.2	3.5	ND	1.9	2.1	2.1	2.1	ND	2.0	2.1

*M/M = originally loaded at medium rate (0.7%), reloaded at medium rate.
+L/H = originally loaded at low rate (0.4%), reloaded at high rate (1.0%).
#N/H = nonacclimated soil loaded at high rate (1.0%).
**N/NR = originally loaded at high rate (1.0%), not reloaded.
++ND = not detected (peak not present).
##Detection limit.

TABLE A-52. CONTINUED

	PAH (mg/kg soil)											
	M/M			L/H			N/H			H/NR		
	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
Naphthalene	317	35	11	290	-	-	273	11.5	4	-	-	-
Fluorene	150	17.3	12	150	-	-	177	11.5	7	100	-	-
Phenanthrene	727	55	8	740	-	-	833	23	3	953	302	32
Anthracene	213	35.1	17	200	10	5	243	110	45	320	187	59
Fluoranthene	590	79.4	13	553	5.8	1	567	11.5	2	510	43.6	9
Pyrene	563	70.2	12	543	5.8	1	573	5.8	1	507	40.4	8
Benzo(a)anthracene	5.3	6.4	12	50.6	1.2	2	52.5	0.7	1	44.8	7.2	16
Chrysene	52.5	5.1	10	48.3	2.1	4	50.5	1	2	45.7	3.2	7
Benzo(b)fluoranthene	21.1	2	10	19.9	1.4	7	20.7	0.4	2	27.5	6.8	30
Benzo(d)fluoranthene	14.5	1.9	13	15.5	2.8	18	3.5	0.1	3	10.8	0.8	8
Benzo(a)pyrene	13.7	1.5	11	14.8	4.9	33	13.2	0.4	3	12.2	1.6	14
Benzo(ghi)perylene	-	-	-	-	-	-	0.7	0.1	20	-	-	-
Dibenz(a,h)anthracene	1.7	0.5	31	4.2	2.5	58	1.6	0.1	7	1.3	0.2	1
Indeno(1,2,3-cd)pyrene	2.2	0.2	7	2.7	1.1	42	2.1	-	0	7.7	9.9	128

TABLE A-53. RESULTS FOR PAH ANALYSIS AT -1/3 BAR SOIL MOISTURE CONTENT FOR CREOSOTE WOOD PRESERVING WASTE REAPPLIED TO KIDMAN SANDY LOAM SOIL (37 DAYS INCUBATION)

	PAH (mg/kg soil)								
	Loading Rate								
	M/M*			L/H+			N/H#		
	Replicate Reactors								
	1	2	3	1	2	3	1	2	3
Naphthalene	560	190	820	330	580	ND**	160	230	250
Fluorene	190	240	260	210	200	270	150	51.9	120
Phenanthrene	820	860	890	830	860	890	560	320	650
Anthracene	460	480	460	320	370	470	190	160	200
Fluoranthene	810	950	900	800	930	960	530	360	410
Pyrene	700	860	770	760	820	ND	530	360	420
Benzo(a)anthracene	58.1	75.3	70.5	70.8	68.8	66.0	50.6	31.5	37.6
Chrysene	70.1	76.2	73.1	70.1	77.6	83.7	50.5	35.9	40.3
Benzo(b)flouranthene	25.4	26.0	25.9	28.5	29.9	ND	19.1	12.0	15.0
Benzo(k)flouranthene	16.8	13.7	17.3	16.1	19.0	ND	10.0	6.1	8.5
Benzo(a)pyrene	13.5	15.2	15.0	17.6	16.2	ND	13.5	5.1	8.0
Benzo(ghi)perylene	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dibenz(a,h)anthracene	1.8	1.8	3.9	1.6	3.6	10.3	1.3++	1.8	1.7
Indeno(1,2,3-cd)pyrene	3.4	3.0	3.5	3.0	3.8	1.8	0.3++	2.1	2.1

*M/M = originally loaded at medium rate (0.7%), reloaded at medium rate.
+L/H = originally loaded at low rate (0.4%), reloaded at high rate (1.0%).
#N/H = nonacclimated soil loaded at high rate (1.0%).
**ND = not detected (peak not present).
++Detection limit.

TABLE A-53. CONTINUED

	PAH (mg/kg soil)								
	M/M			L/H			N/H		
	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
Naphthalene	523	317	60	303	291	96	160	138	86
Fluorene	230	36	16	227	38	17	111	54.6	49
Phenanthrene	857	35	4	860	30	3	373	254	68
Anthracene	467	11.5	2	387	76.4	20	307	220	72
Fluoranthene	887	70.9	8	897	85	9	320	115	36
Pyrene	776	80.2	10	527	457	87	437	86.2	20
Benzo(a)anthracene	67.9	8.8	13	68.5	2.4	4	200	286	143
Chrysene	73	3	4	77.1	6.8	9	42.3	7.5	18
Benzo(b)fluoranthene	25.7	0.3	1	19.5	16.9	87	25.8	21.4	83
Benzo(k)fluoranthene	15.9	1.9	12	11.7	10.2	87	11.2	6.9	62
Benzo(a)pyrene	14.5	0.9	6	11.2	9.8	87	7.7	2.5	32
Benzo(ghi)perylene	-	-	-	-	-	-	4.5	7.8	173
Dibenz(a,h)anthracene	2.5	1.2	49	5.1	4.5	88	1.2	1	87
Indeno(a,2,3-cd)pyrene	3.3	0.3	8	2.8	1	35	1.8	0.5	26

TABLE A-54. RESULTS FOR PAH ANALYSIS AT -1/3 BAR SOIL MOISTURE CONTENT FOR CREOSOTE WOOD PRESERVING WASTE REAPPLIED TO KIDMAN SANDY LOAM SOIL (74 DAYS INCUBATION)

	PAH (mg/kg soil)											
	Loading Rate											
	M/M*			L/H+			N/H#			H/NR**		
	Replicate Reactors											
	1	2	3	1	2	3	1	2	3	1	2	3
Naphthalene	ND++	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Fluorene	82.8	120	210	0.2	140	200	33.0	57.5	42.0	56.6	66.6	93.1
Phenanthrene	430	530	670	1.7	580	670	65.5	180	80.4	390	530	580
Anthracene	160	160	280	0.17	170	250	70.0	110	86.2	110	92.4	190
Fluoranthene	410	620	160	110	730	120	260	400	330	300	410	480
Pyrene	320	410	900	56.1	500	690	200	310	260	270	370	420
Benzo(a)anthracene	38.4	46.1	83.8	24.4	56.7	77.5	26.7	38.7	35.6	27.5	37.4	43.3
Chrysene	39.5	47.9	85.7	5.8	58.9	77.4	27.9	40.2	36.0	26.8	35.8	42.8
Benzo(b)flouranthene	12.6	13.6	23.7	ND	17.9	24.9	8.6	12.9	13.0	10.1	13.5	15.4
Benzo(k)flouranthene	8.8	7.8	13.2	ND	11.2	20.4	6.5	10.1	12.3	9.2	12.2	ND
Benzo(a)pyrene	12.9	8.0	12.9	0.15	12.6	17.6	5.5	8.8	13.0	9.5	13.4	16.9
Benzo(ghi)perylene	26.9	ND	ND	ND	2.4	ND	0.8	ND	0.6##	14.3	25.1	48.1
Dibenz(a,h)anthracene	13.0	4.1	5.8	ND	2.6	4.4	1.3	2.2	7.1	5.0	11.1	12.6
Indeno(1,2,3-cd)pyrene	59.9	2.0	3.6	0.3##	2.4	4.0	1.4	2.2	3.5	3.8	3.9	12.6

*M/M = originally loaded at medium rate (0.7%), reloaded at medium rate.
+L/H = originally loaded at low rate (0.4%), reloaded at high rate (1.0%).
#N/H = nonacclimated soil loaded at high rate (1.0%).
**N/NR = originally loaded at high rate (1.0%), not reloaded.
++ND = not detected (peak not present).
##Detection limit.

TABLE A-54. CONTINUED

	PAH (mg/kg soil)											
	M/M			L/H			N/H			H/NR		
	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
Naphthalene	-	-	-	-	-	-	-	-	-	-	-	-
Fluorene	138	65.4	48	113	102	90	44.2	12.4	28	72.1	18.9	26
Phenanthrene	543	121	22	417	362	87	109	62.9	57	500	98.5	20
Anthracene	200	69.3	34	140	128	91	88.7	20	23	131	52	40
Fluoranthene	397	230	58	320	355	111	330	70	21	397	90.7	23
Pyrene	543	312	57	415	325	78	257	55	22	353	76.4	22
Benzo(a)anthracene	56.1	24.3	43	52.8	26.8	51	33.6	6.7	19	36	8	22
Chrysene	72	20.9	29	47.3	37.2	78	34.7	6.3	18	35.1	8	23
Benzo(b)fluoranthene	16.6	6.2	37	14.3	12.8	90	11.5	2.5	22	13	2.7	21
Benzo(d)fluoranthene	9.9	2.9	29	10.5	10.2	97	9.6	2.9	30	7.1	6.3	89
Benzo(a)pyrene	11.3	2.8	25	10.1	9	89	9.1	3.8	41	13.3	3.7	28
Benzo(ghi)perylene	9	15.5	173	0.8	1.4	173	0.5	0.4	90	29.1	17.2	59
Dibenz(a,h)anthracene	7.6	4.7	62	2.3	2.2	95	3.5	3.1	88	9.6	4	42
Indeno(1,2,3-cd)pyrene	2.9	0.8	28	2.2	1.9	83	2.4	1.0	45	6.8	5	75

TABLE A-55. RESULTS FOR PAH ANALYSIS AT -1/3 BAR SOIL MOISTURE CONTENT FOR CREOSOTE WOOD PRESERVING WASTE REAPPLIED TO KIDMAN SANDY LOAM SOIL (102 DAYS INCUBATION)

	PAH (mg/kg soil)								
	Loading Rate								
	M/M*			L/H+			N/H#		
	Replicate Reactors								
	1	2	3	1	2	3	1	2	3
Naphthalene	ND**	ND	ND	ND	ND	ND	ND	ND	ND
Fluorene	5.3	42.0	58.7	41.3	16.7	37.7	9.8	11.8	10.0
Phenanthrene	400	290	360	260	52.9	170	15.0	16.7	10.2
Anthracene	150	130	210	81.8	59.4	110	49.4	68.6	46.8
Fluoranthene	400	430	420	230	130	300	220	150	200
Pyrene	330	360	340	190	120	260	160	130	170
Benzo(a)anthracene	39.2	45.5	42.7	24.5	15.8	33.8	26.0	21.6	33.9
Chrysene	46.2	51.2	48.2	27.8	21.7	43.4	30.5	26.8	39.2
Benzo(b)flouranthene	15.2	16.8	15.3	9.2	5.5	12.5	9.6	8.5	13.0
Benzo(k)flouranthene	13.5	15.0	14.5	7.9	4.6	12.3	8.2	6.4	12.0
Benzo(a)pyrene	11.0	12.0	11.8	7.6	3.6	12.4	6.4	5.1	12.8
Benzo(ghi)perylene	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dibenz(a,h)anthracene	1.9	2.2	2.2	1.3++	1.3++	2.1	1.7	1.7	2.2
Indeno(1,2,3-cd)pyrene	2.0	2.3	1.9	1.1	0.64	2.1	1.5	1.2	1.9

*M/M = originally loaded at medium rate (0.7%), reloaded at medium rate.
+L/H = originally loaded at low rate (0.4%), reloaded at high rate (1.0%).
#N/H = nonacclimated soil loaded at high rate (1.0%).
**ND = not detected (peak not present).
++Detection limit.

TABLE A-55. CONTINUED

	PAH (mg/kg soil)								
	M/M			L/H			N/H		
	x̄	SD	CV	x̄	SD	CV	x̄	SD	CV
Naphthalene	-	-	-	-	-	-	-	-	-
Fluorene	35.3	27.3	77	31.9	13.3	42	10.5	1.1	10
Phenanthrene	350	55.7	16	161	104	65	14	3.4	24
Anthracene	163	91.6	26	83.7	25.4	30	55	11.9	22
Fluoranthene	417	15.3	4	220	85.5	39	190	36	19
Pyrene	393	15.3	4	190	70	37	153	20.8	14
Benzo(a)anthracene	42.4	3.2	7	24.7	9	36	27.2	6.2	23
Chrysene	48.5	2.5	5	31	11.2	36	32.2	6.4	20
Benzo(b)fluoranthene	15.7	0.9	6	9	3.5	39	10.4	2.3	23
Benzo(k)fluoranthene	14.3	0.7	5	8.3	3.8	47	8.9	2.9	32
Benzo(a)pyrene	11.6	0.5	5	7.9	4.4	6	8.1	4.1	51
Benzo(ghi)perylene	-	-	-	-	-	-	-	-	-
Dibenz(a,h)anthracene	2.1	0.2	8	1.5	0.5	31	1.8	0.3	15
Indeno(a,2,3-cd)pyrene	2	0.2	10	1.2	0.7	58	1.5	0.3	20

TABLE A-56. RESULTS FOR PAH ANALYSIS AT -1 BAR SOIL MOISTURE CONTENT FOR PENTACHLOROPHENOL WOOD PRESERVING WASTE REAPPLIED TO DURANT CLAY LOAM SOIL (IMMEDIATELY AFTER WASTE ADDITION)

	PAH (mg/kg soil)					
	Loading Rate					
	M/M[*]			H/NR[+]		
	Replicate Reactors					
	1	2	3	1	2	3
Naphthalene	ND[#]	ND	ND	ND	ND	ND
Fluorene	69.2	140	160	44.7	29.4	21.5
Phenanthrene	410	690	710	180	340	78.9
Anthracene	130	230	490	80.0	130	38.8
Fluoranthene	250	380	350	190	250	89.5
Pyrene	260	450	410	210	250	100
Benzo(a)anthracene	13.1	39.1	33.4	19.1	20.6	8.8
Chrysene	21.9	58.0	57.6	28.3	33.9	14.4
Benzo(b)fluoranthene	8.6	24.2	21.9	17.1	10.9	8.8
Benzo(k)fluoranthene	3.3	12.8	10.5	5.2	4.0	2.9
Benzo(a)pyrene	5.7	11.7	9.8	4.9	4.4	2.4
Benzo(ghi)perylene	ND	ND	ND	ND	1.6	0.6[**]
Dibenz(a,h)anthracene	1.3	2.4	3.2	ND	1.6	ND
Indeno(1,2,3-cd)pyrene	1.8	2.0	2.3	0.4	1.5	0.7

[*] M/M = originally loaded at medium rate (0.5%), reloaded at medium rate.

[+] H/NR = originally loaded at high rate (0.7%), not reloaded.

[#] ND = not detected (peak not present).

[**] Detection limit.

TABLE A-56. CONTINUED

	PAH (mg/kg soil)					
	M/M			H/NR		
	x̄	SD	CV	x̄	SD	CV
Naphthalene	-	-	-	-	-	-
Fluorene	121	51.3	42	31.9	11.8	37
Phenanthrene	603	168	28	200	132	66
Anthracene	283	186	66	83	45.7	55
Fluoranthene	327	681	21	177	81.1	46
Pyrene	373	100	27	187	77.7	42
Benzo(a)anthracene	28.5	13.7	48	16.2	6.4	40
Chrysene	45.8	20.7	45	25.5	10	39
Benzo(b)fluoranthene	18.2	8.4	46	12.3	4.3	35
Benzo(k)fluoranthene	8.9	4.9	56	4	1.2	29
Benzo(a)pyrene	9.1	3.1	34	3.9	1.3	34
Benzo(ghi)perylene	-	-	-	0.72	0.8	113
Dibenz(a,h)anthracene	2.3	1	42	0.5	0.9	173
Indeno(1,2,3-cd)pyrene	2	0.3	12	0.9	0.6	66

TABLE A-57. RESULTS FOR PAH ANALYSIS AT -1 BAR SOIL MOISTURE CONTENT FOR PENTACHLOROPHENOL WOOD PRESERVING WASTE REAPPLIED TO DURANT CLAY LOAM SOIL (37 DAYS INCUBATION)

	PAH (mg/kg soil)		
	Loading Rate		
	M/M*		
	Replicate Reactors		
	1	2	3
Naphthalene	ND+	ND	ND
Fluorene	140	140	130
Phenanthrene	640	670	640
Anthracene	250	280	210
Fluoranthene	480	220	480
Pyrene	410	440	410
Benzo(a)anthracene	47.1	46.1	46.2
Chrysene	65.3	65.7	65.4
Benzo(b)fluoranthene	32.5	25.5	30.3
Benzo(k)fluoranthene	23.5	17.0	24.3
Benzo(a)pyrene	32.2	14.3	30.6
Benzo(ghi)perylene	44.8	ND	33.9
Dibenz(a,h)anthracene	18.2	3.0	15.1
Indeno(1,2,3-cd)pyrene	7.7	2.6	7.4

*M/M = originally loaded at medium rate (0.5%), reloaded at medium rate.
+ND = not detected (peak not present).

TABLE A-57. CONTINUED

	PAH (mg/kg soil)		
	M/M		
	$\bar{\bar{x}}$	SD	CV
Naphthalene	-	-	-
Fluorene	137	5.8	4
Phenanthrene	650	17.3	3
Anthracene	247	35.1	14
Fluoranthene	393	150	38
Pyrene	420	17.3	4
Benzo(a)anthracene	46.5	0.6	1
Chrysene	65.5	0.2	0.3
Benzo(b)fluoranthene	29.4	3.6	12
Benzo(k)fluoranthene	21.6	4	19
Benzo(a)pyrene	25.7	9.9	39
Benzo(ghi)perylene	26.2	23.4	89
Dibenz(a,h)anthracene	12.1	8	66
Indeno(1,2,3-cd)pyrene	59	2.9	49

TABLE A-58. RESULTS FOR PAH ANALYSIS AT -1 BAR SOIL MOISTURE CONTENT FOR PENTACHLOROPHENOL WOOD PRESERVING WASTE REAPPLIED TO DURANT CLAY LOAM SOIL (74 DAYS INCUBATION)

	PAH (mg/kg soil)					
	Loading Rate					
	M/M*			H/NR+		
	Replicate Reactors					
	1	2	3	1	2	3
Naphthalene	ND#	ND	ND	ND	ND	ND
Fluorene	46.0	100	38.2	2.2	1.8	ND
Phenanthrene	150	560	78.0	6.0	5.4	ND
Anthracene	120	210	160	7.9	7.7	ND
Fluoranthene	350	430	350	110	62.3	ND
Pyrene	320	410	300	83.6	49.8	0.2
Benzo(a)anthracene	42.9	46.3	48.6	18.9	11.0	ND
Chrysene	50.4	58.8	58.6	23.8	14.1	ND
Benzo(b)fluoranthene	22.3	26.0	25.4	10.4	9.6	ND
Benzo(k)fluoranthene	14.2	17.3	17.3	5.9	3.2	ND
Benzo(a)pyrene	13.2	15.7	15.8	5.4	2.8	ND
Benzo(ghi)perylene	ND	ND	ND	ND	0.6**	ND
Dibenz(a,h)anthracene	3.0	2.9	3.2	1.3**	1.3**	ND
Indeno(1,2,3-cd)pyrene	3.5	3.3	3.9	1.2	0.9	ND

*M/M = originally loaded at medium rate (0.5%), reloaded at medium rate.
+H/NR = originally loaded at high rate (0.7%), not reloaded.
#ND = not detected (peak not present).
**Detection limit.

TABLE A-58. CONTINUED

	PAH (mg/kg soil)					
	M/M			H/NR		
	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
Naphthalene	-	-	-	-	-	-
Fluorene	61.4	33.7	55	1.3	1.2	88
Phenanthrene	263	260	99	3.8	3.3	87
Anthracene	163	45.1	28	5.2	4.5	87
Fluoranthene	377	46.2	12	57.4	55.2	96
Pyrene	343	58.6	17	44.5	41.9	94
Benzo(a)anthracene	45.9	2.9	6	10	9.5	95
Chrysene	55.9	4.8	8.5	12.6	12	95
Benzo(b)fluoranthene	24.6	2	8	6.7	5.8	89
Benzo(k)fluoranthene	16.3	1.8	11	3	2.9	97
Benzo(a)pyrene	14.9	1.5	10	2.7	2.7	99
Benzo(ghi)perylene	-	-	-	0.2	0.3	173
Dibenz(a,h)anthracene	3	0.2	5	0.8	0.7	87
Indeno(1,2,3-cd)pyrene	3.6	0.3	9	0.7	0.6	89

TABLE A-59. RESULTS FOR PAH ANALYSIS AT -1 BAR SOIL MOISTURE CONTENT FOR PENTACHLOROPHENOL WOOD PRESERVING WASTE REAPPLIED TO DURANT CLAY LOAM SOIL (102 DAYS INCUBATION)

	PAH (mg/kg soil)		
	Loading Rate		
	M/M[*]		
	Replicate Reactors		
	1	2	3
Naphthalene	ND[+]	ND	ND
Fluorene	15.6	18.0	32.1
Phenanthrene	13.9	16.3	25.9
Anthracene	50.1	41.8	89.1
Fluoranthene	300	280	420
Pyrene	270	260	370
Benzo(a)anthracene	58.2	51.8	72.7
Chrysene	59.4	53.0	74.5
Benzo(b)fluoranthene	25.2	22.0	31.8
Benzo(k)fluoranthene	18.7	16.6	22.6
Benzo(a)pyrene	18.0	15.8	21.9
Benzo(ghi)perylene	ND	ND	ND
Dibenz(a,h)anthracene	2.6	2.0	3.4
Indeno(1,2,3-cd)pyrene	3.0	2.3	3.7

[*] M/M = originally loaded at medium rate (0.5%), reloaded at medium rate.

[+] ND = not detected (peak not present).

TABLE A-59. CONTINUED

	PAH (mg/kg soil) M/M		
	x̄	SD	CV
Naphthalene	-	-	-
Fluorene	21.9	8.9	41
Phenanthrene	18.7	6.3	34
Anthracene	60.3	25.3	42
Fluoranthene	333	75.7	23
Pyrene	300	60.8	20
Benzo(a)anthracene	60.9	10.7	18
Chrysene	67.3	11	18
Benzo(b)fluoranthene	26.3	5	19
Benzo(k)fluoranthene	19.3	3	16
Benzo(a)pyrene	18.6	3.1	16
Benzo(ghi)perylene	-	-	-
Dibenz(a,h)anthracene	2.7	0.7	26
Indeno(1,2,3-cd)pyrene	3	0.7	23

TABLE A-60. CONTINUED

	PAH (mg/kg soil)											
	M/M			L/H			N/H			H/NR		
	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
Naphthalene	-	-	-	-	-	-	-	-	-	-	-	-
Fluorene	29.7	2.9	10	34.3	29.9	87	49.2	1.7	3	7.3	6.8	92
Phenanthrene	83.7	10.1	12	86.7	75.7	87	120	-	-	41.2	34.1	83
Anthracene	41.6	3.8	9	50.5	44.5	88	69.4	7.2	10	15.4	13.5	88
Fluoranthene	92.4	11	12	96.7	83.9	87	73.3	63.5	87	53.1	45.5	86
Pyrene	97.4	14	14	107	92.4	87	143	5.8	4	57.8	49.4	85
Benzo(a)anthracene	9.9	1.2	12	7.9	7.2	91	14	1.6	11	5.6	5	89
Chrysene	13.6	1.5	11	11.7	10.2	87	20.7	1.8	9	8.3	6.7	80
Benzo(b)fluoranthene	5.5	0.8	13	1.9	3.2	173	8	1.5	19	3.8	3.3	87
Benzo(d)fluoranthene	2.7	0.4	15	0.5	0.8	173	2.6	2.5	94	1.5	1.4	94
Benzo(a)pyrene	2.4	0.3	13	1	1.6	160	4.8	0.3	6	1.0	1.0	94
Benzo(ghi)perylene	0.8	0.5	56	-	-	-	-	-	-	0.2	0.3	173
Dibenz(a,h)anthracene	0.4	0.7	173	9.2	7.3	173	-	-	-	-	-	-
Indeno(1,2,3-cd)pyrene	0.4	0.1	34	2.5	4.4	173	2.8	3.4	139	0.2	0.4	173

TABLE A-60. RESULTS FOR PAH ANALYSIS AT -1/3 BAR SOIL MOISTURE CONTENT FOR PENTACHLOROPHENOL WOOD PRESERVING WASTE REAPPLIED TO KIDMAN SANDY LOAM SOIL (IMMEDIATELY AFTER WASTE ADDITION)

PAH (mg/kg soil)	Loading Rate											
	M/M*			L/H+			N/H#			H/NR**		
	Replicate Reactors											
	1	2	3	1	2	3	1	2	3	1	2	3
Naphthalene	ND++	ND	ND	ND	ND	0.3	ND	ND	ND	ND	ND	ND
Flourene	29.7	32.6	26.8	48.1	54.9	ND	50.8	47.5	49.3	13.9	7.7	0.4
Phenanthrene	87.1	91.6	72.3	120	140	ND	120	120	120	66.4	54.7	2.4
Anthracene	37.2	43.9	43.7	84.2	67.2	ND	77.4	63.4	67.3	26.1	19.9	0.2##
Fluoranthene	97.3	100	79.8	150	140	ND	ND	110	110	87.7	69.9	1.6
Pyrene	100	110	82.3	160	160	ND	140	140	150	94.7	77.0	1.7
Benzo(a)anthracene	10.3	10.8	8.6	9.8	14.0	ND	15.6	12.5	14.0	9.5	7.2	ND
Chrysene	14.1	14.9	12.0	16.2	18.9	ND	22.7	19.7	19.6	13.2	11.0	ND
Benzo(b)flouranthene	5.7	6.1	4.7	ND	5.6	ND	9.6	7.8	6.6	5.4	6.0	ND
Benzo(k)flouranthene	2.7	3.1	2.3	ND	1.4	ND	4.9	3.0	ND	2.8	1.7	ND
Benzo(a)pyrene	2.5	2.7	2.1	ND	2.9	0.2##	5.1	4.5	4.8	1.8	1.1	ND
Benzo(ghi)perylene	1.4	0.6	0.6##	ND	ND	ND	ND	ND	ND	0.6##	ND	ND
Dibenz(a,h)anthracene	ND	ND	ND	170	ND	ND	ND	ND	ND	ND	ND	ND
Indeno(1,2,3-cd)pyrene	0.5	0.3##	0.3##	95.1	ND	ND	0.5	0.6	7.3	ND	0.7	ND

*M/M = originally loaded at medium rate (0.15%), reloaded at medium rate.
+L/H = originally loaded at low rate (0.075%), reloaded at high rate (0.3%).
#N/H = nonacclimated soil loaded at high rate (0.3%).
**N/NR = originally loaded at high rate (0.3%), not reloaded.
++ND = not detected (peak not present).
##Detection limit.

TABLE A-61. RESULTS FOR PAH ANALYSIS AT -1/3 BAR SOIL MOISTURE CONTENT FOR PENTACHLOROPHENOL WOOD PRESERVING WASTE REAPPLIED TO KIDMAN SANDY LOAM SOIL (37 DAYS INCUBATION)

	PAH (mg/kg soil)								
	Loading Rate								
	M/M*			L/H^{+}			N/H$^{\#}$		
	Replicate Reactors								
	1	2	3	1	2	3	1	2	3
Naphthalene	ND**	ND	0.3^{++}	ND	ND	ND	ND	ND	ND
Fluorene	3.9	ND	25.0	53.1	54.8	0.5	30.3	33.8	32.0
Phenanthrene	14.2	1.13	87.2	160	180	2.5	100	110	97.9
Anthracene	3.9	0.2^{++}	40.0	76.6	65.5	0.2^{++}	40.2	38.2	40.3
Fluoranthene	18.0	ND	120	180	190	1.4	120	120	110
Pyrene	16.1	ND	110	170	180	1.1	110	110	110
Benzo(a)anthracene	0.8^{++}	0.8^{++}	13.2	20.9	21.4	ND	12.4	11.8	12.3
Chrysene	2.8	ND	16.2	24.2	24.6	ND	14.8	15.0	14.5
Benzo(b)flouranthene	2.0	ND	6.8	10.8	11.3	ND	6.9	7.1	11.8
Benzo(k)flouranthene	0.5	ND	4.6	7.4	7.3	ND	4.3	4.3	4.3
Benzo(a)pyrene	0.3	ND	3.5	6.0	6.0	ND	3.7	3.7	3.8
Benzo(ghi)perylene	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dibenz(a,h)anthracene	ND	ND	1.3^{++}	ND	1.4	ND	ND	ND	1.3^{++}
Indeno(1,2,3-cd)pyrene	0.3^{++}	ND	0.7	1.5	1.2	ND	0.4	0.3^{++}	0.5

*M/M = originally loaded at medium rate (0.15%), reloaded at medium rate.
$^{+}$L/H = originally loaded at low rate (0.075%), reloaded at high rate (1.0%).
$^{\#}$N/H = nonacclimated soil loaded at high rate (0.3%).
**ND = not detected (peak not present).
$^{++}$Detection limit.
$^{++}$- = not analyzed.

TABLE A-61. CONTINUED

	PAH (mg/kg soil)								
	M/M			L/H			N/H		
	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
Naphthalene	-	-	-	-	-	-	-	-	-
Fluorene	9.6	13.4	139	36.4	30.9	85	32	1.8	5
Phenanthrene	34.2	46.4	135	114	97.2	85	103	6.5	6
Anthracene	14.7	22	149	47.4	41.4	87	39.6	1.2	3
Fluoranthene	46	64.7	140	124	106	86	117	5.8	5
Pyrene	42	59.4	141	117	101	86	110	-	-
Benzo(a)anthracene	4.7	7.4	159	14.1	12.2	87	12.2	0.3	3
Chrysene	6.3	8.7	136	16.3	14.1	87	14.7	0.3	2
Benzo(b)fluoranthene	3.6	2.8	77	7.4	6.4	87	8.6	2.8	32
Benzo(k)fluoranthene	1.8	2.4	134	4.9	4.2	87	4.3	-	-
Benzo(a)pyrene	1.3	1.9	153	4	3.5	87	3.7	0.06	2
Benzo(ghi)perylene	-	-	-	-	-	-	-	-	-
Dibenz(a,h)anthracene	0.5	0.7	127	0.5	0.8	173	-	-	-
Indeno(a,2,3-cd)pyrene	0.5	0.3	59	1	0.6	63	0.4	0.1	26

TABLE A-62. RESULTS FOR PAH ANALYSIS AT -1/3 BAR SOIL MOISTURE CONTENT FOR PENTACHLOROPHENOL WOOD PRESERVING WASTE REAPPLIED TO KIDMAN SANDY LOAM SOIL (74 DAYS INCUBATION)

	PAH (mg/kg soil)											
	Loading Rate											
	M/M*			L/H+			N/H#			H/NR**		
	Replicate Reactors											
	1	2	3	1	2	3	1	2	3	1	2	3
Naphthalene	ND++	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Flourene	0.9	1.9	15.6	20.4	ND	ND	9.3	27.6	15.9	ND	3.6	1.3
Phenanthrene	3.2	9.3	63.3	40.4	ND	1.1	44.8	99.7	75.2	3.3	5.0	4.2
Anthracene	2.2	4.0	44.3	54.8	0.2	ND	21.7	41.3	31.6	11.6	22.1	18.8
Fluoranthene	14.7	12.6	110	110	ND	ND	47.8	110	82.0	38.3	63.4	64.1
Pyrene	15.3	12.0	93.0	120	ND	ND	43.4	100	73.8	4.1	53.9	54.4
Benzo(a)anthracene	2.6	1.8	12.8	17.8	ND	ND	4.9	11.1	8.0	9.3	11.1	12.2
Chrysene	3.2	2.2	15.3	20.1	ND	ND	6.4	14.8	11.2	12.4	14.3	15.8
Benzo(b)flouranthene	2.5	1.6	6.7	9.4	ND	ND	4.2	10.5	7.2	7.8	9.1	5.8
Benzo(k)flouranthene	0.6	0.3	4.0	5.9	ND	ND	1.1	3.3	2.2	2.8	3.2	3.7
Benzo(a)pyrene	0.3	0.2	2.8	4.8	ND	ND	0.7	2.3	1.3	1.6	1.8	2.0
Benzo(ghi)perylene	ND	ND	0.6##	ND	ND	ND	0.6##	ND	0.9	1.0	ND	ND
Dibenz(a,h)anthracene	ND	ND	1.3##	1.3##	ND	ND	ND	1.3##	1.3##	1.3##	ND	1.3##
Indeno(1,2,3-cd)pyrene	0.3	0.3##	0.6	0.8	ND	ND	0.4	0.5	0.5	0.5	0.5	0.7

*M/M = originally loaded at medium rate (0.15%), reloaded at medium rate.
+L/H = originally loaded at low rate (0.075%), reloaded at high rate (0.3%).
#N/H = nonacclimated soil loaded at high rate (0.3%).
**N/NR = originally loaded at high rate (0.3%), not reloaded.
++ND = not detected (peak not present).
##Detection limit.

TABLE A-62. CONTINUED

	PAH (mg/kg soil)											
	M/M			L/H			N/H			H/NR		
	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
Naphthalene	-	-	-	-	-	-	-	-	-	-	-	-
Fluorene	6.1	8.2	134	6.8	11.8	173	17.6	9.3	53	1.6	1.8	111
Phenanthrene	25.3	33.1	130	13.9	23	166	73.2	27.5	38	4.2	0.8	20
Anthracene	16.8	23.8	141	18.3	31.6	172	31.5	9.8	31	17.5	5.4	31
Fluoranthene	45.8	55.7	121	36.7	63.5	173	79.9	31.2	39	55.3	14.7	27
Pyrene	40.1	45.8	114	40	69.3	173	72.4	28.3	39	37.5	28.9	77
Benzo(a)anthracene	5.7	6.2	106	5.9	10.2	173	8	3.1	39	10.9	1.5	13
Chrysene	6.9	7.3	105	6.7	11.6	173	10.8	4.2	39	14.2	1.7	12
Benzo(b)fluoranthene	3.6	2.7	75.6	3.1	5.4	173	7.3	3.1	43	7.6	1.7	22
Benzo(d)fluoranthene	1.6	2	125	2	3.4	173	2.2	1.1	50	3.2	0.5	14
Benzo(a)pyrene	1.1	1.4	134	1.6	2.8	173	1.4	0.8	56	1.8	0.2	11
Benzo(ghi)perylene	0.2	0.3	173	-	-	-	0.5	0.4	93	0.3	0.6	173
Dibenz(a,h)anthracene	0.4	0.7	173	0.4	0.7	173	0.8	0.7	87	0.8	0.7	87
Indeno(1,2,3-cd)pyrene	0.4	0.2	44	0.3	0.5	173	0.5	0.06	12	0.6	0.1	20

TABLE A-63. RESULTS FOR PAH ANALYSIS AT -1/3 BAR SOIL MOISTURE CONTENT FOR PENTACHLOROPHENOL WOOD PRESERVING WASTE REAPPLIED TO KIDMAN SANDY LOAM SOIL (102 DAYS INCUBATION)

	PAH (mg/kg soil)								
	Loading Rate								
	M/M*			L/H+			N/H#		
	Replicate Reactors								
	1	2	3	1	2	3	1	2	3
Naphthalene	ND**	ND	ND	ND	ND	ND	ND	ND	ND
Fluorene	4.5	3.9	11.0	10.0	6.6	9.2	9.3	19.2	17.4
Phenanthrene	6.4	43.1	16.4	21.4	3.6	9.4	8.4	90.4	81.9
Anthracene	28.7	32.7	40.4	63.7	36.8	55.8	36.9	42.3	53.3
Fluoranthene	91.0	100	69.6	140	100	94.2	77.7	120	140
Pyrene	75.3	100	73.9	160	100	110	83.5	120	130
Benzo(a)anthracene	18.0	16.8	16.0	31.2	20.1	20.3	17.1	16.9	18.8
Chrysene	18.3	16.8	15.9	30.1	20.4	21.1	17.0	17.4	19.0
Benzo(b)flouranthene	7.7	6.7	6.7	12.7	8.3	8.7	6.7	6.6	7.2
Benzo(k)flouranthene	6.8	5.2	5.2	10.1	6.5	6.3	4.8	5.0	5.7
Benzo(a)pyrene	5.5	4.3	4.3	9.2	5.6	5.3	4.2	3.9	4.9
Benzo(ghi)perylene	4.5	0.6	ND	ND	ND	ND	ND	ND	ND
Dibenz(a,h)anthracene	2.7	ND	ND	1.3++	ND	ND	ND	ND	ND
Indeno(1,2,3-cd)pyrene	1.4	0.7	0.6	1.5	0.8	0.8	0.6	0.6	0.6

*M/M = originally loaded at medium rate (0.15%), reloaded at medium rate.
+L/H = originally loaded at low rate (0.075%), reloaded at high rate (1.0%).
#N/H = nonacclimated soil loaded at high rate (0.3%).
**ND = not detected (peak not present).
++Detection limit.

TABLE A-63. CONTINUED

	PAH (mg/kg soil)								
	M/M			L/H			N/H		
	x̄	SD	CV	x̄	SD	CV	x̄	SD	CV
Naphthalene	-	-	-	-	-	-	-	-	-
Fluorene	6.5	3.9	61	8.6	1.8	21	15.3	5.3	35
Phenanthrene	22	19	86	11.5	9.1	79	60.2	45.1	65
Anthracene	33.9	5.9	18	52.1	13.9	27	44.2	8.4	19
Fluoranthene	86.9	15.6	18	111	24.9	22	113	31.8	28
Pyrene	83.1	14.7	18	123	32.1	26	111	24.5	22
Benzo(a)anthracene	16.7	1	6	23.9	6.3	27	17.6	1	6
Chrysene	17	1.2	7	23.9	5.4	23	17.8	1	6
Benzo(b)fluoranthene	7.1	0.6	8	9.9	2.4	25	6.8	0.3	5
Benzo(k)fluoranthene	5.7	0.9	16	7.6	2.1	28	5.2	0.5	9
Benzo(a)pyrene	4.7	0.7	15	6.7	2.2	0.3	4.3	0.5	12
Benzo(ghi)perylene	1.7	2.4	143	-	-	-	-	-	-
Dibenz(a,h)anthracene	1.7	0.8	47	0.4	0.7	173	-	-	0
Indeno(a,2,3-cd)pyrene	0.9	0.4	48	1	0.4	39	0.6	-	-

TABLE A-64 . RESULTS FOR PENTACHLOROPHENOL ANALYSIS WITH INCUBATION TIME FOR PENTACHLOROPHENOL WOOD PRESERVING WASTE MIXED WITH DURANT CLAY LOAM AT -1 BAR

Time (days)	PCP (mg/kg soil)					
	Loading Rate					
	M/M*			H/NR+		
	Replicate Reactors					
	1	2	3	1	2	3
0	390	410	-#	220	230	-
37	320	330	-	-	-	-
74	340	340	-	210	270	-
102	99	83	-	-	-	-
164	330	330	410	370	34	270

*M/M = originally loaded at medium rate (0.5%), reloaded at medium rate.
+H/NR = originally loaded at high rate (0.7%), not reloaded.
#- = not analyzed.

TABLE A-64 . CONTINUED

Time (days)	PCP (mg/kg soil) Loading Rate M/M* $\bar{x}$	SD	CV	H/NR+ $\bar{x}$	SD	CV
0	400	14	3.5	220	7.1	3.2
37	320	7.1	2.2	-#	-	-
74	340	0	0	240	42	18
102	91	11	12	-	-	-
164	360	46	13	220	170	77

*M/M = originally loaded at medium rate (0.5%), reloaded at medium rate.
+H/NR = originally loaded at high rate (0.7%), not reloaded.
#- = not analyzed.

TABLE A-65. RESULTS FOR PENTACHLOROPHENOL ANALYSIS WITH INCUBATION TIME FOR PENTACHLOROPHENOL WOOD PRESERVING WASTE MIXED WITH KIDMAN SANDY LOAM AT -1/3 BAR

Time (days)	PCP (mg/kg soil)											
	Loading Rate											
	M/M*			L/H⁺			N/H#			H/NR**		
	Replicate Reactors											
	1	2	3	1	2	3	1	2	3	1	2	3
0	270	-++	-	160	160	-	-	-	-	120	240	-
37	140	150	-	220	190	-	130	140	-	-	-	-
74	210	140	-	190	200	-	140	160	-	110	160	-
102	150	150	-	210	170	-	140	140	-	-	-	-
164	120	110	200	95	96	64	130	110	93	95	95	100

*M/M = originally loaded at medium rate (0.15%), reloaded at medium rate.

⁺L/H = originally loaded at low rate (0.075%), reloaded at high rate (0.3%).

#N/H = nonacclimated soil loaded at high rate (0.3%).

**H/NR = originally loaded at high rate (0.3%), not reloaded.

++- = not analyzed.

TABLE A-65. CONTINUED

Time (days)	PCP (mg/kg soil)											
	Loading Rate											
	M/M[*]			L/H[+]			N/H[#]			H/NR[**]		
	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV	$\bar{x}$	SD	CV
0	270	-[++]	-	160	0	0	-	-	-	180	85	47
37	140	7.1	5.1	200	21	11	140	7.1	5.1	-	-	-
74	180	50	28	200	7.1	3.6	150	14	9.3	140	35	25
102	150	0	0	190	28	15	140	0	0	-	-	-
164	140	49	35	85	18	21	110	18	15	97	2.9	3.0

[*] M/M = originally loaded at medium rate (0.15%), reloaded at medium rate.
[+] L/H = originally loaded at low rate (0.075%), reloaded at high rate (0.3%).
[#] N/H = nonacclimated soil loaded at high rate (0.3%).
[**] H/NR = originally loaded at high rate (0.3%), not reloaded.
[++] - = not analyzed.

TABLE A- 66. RESULTS FOR PH VALUES WITH INCUBATION TIME AT LOW SOIL MOISTURE CONTENT FOR CREOSOTE WASTE MIXED WITH DURANT CLAY LOAM SOIL

Sample Time (day)	pH Values Replicate Reactors 1	2	3
	Load Rate (% waste wet/soil dry) 0.7%		
0	6.7	6.4	6.4
37	6.6	6.4	6.4
234	7.9	7.2	7.0
	Load Rate (% waste wet/soil dry) 1%		
0	6.6	6.5	6.5
37	6.5	6.5	6.4
234	7.5	7.1	7.3
	Load Rate (% waste wet/soil dry) 1.3%		
0	6.4	6.5	6.4
37	6.8	6.5	6.4
234	7.8	7.3	6.9
	Control		
0	6.6	6.6	6.4
37	6.7	6.4	6.4
234	6.6	6.4	6.6

TABLE A-67. RESULTS FOR PH VALUES WITH INCUBATION TIME AT LOW SOIL MOISTURE CONTENT FOR CREOSOTE WASTE MIXED WITH KIDMAN SANDY LOAM SOIL

Sample time (day)	pH Values Replicate Reactors 1	2	3
	Load Rate (% waste wet/soil dry) 0.4%		
0	7.7	7.6	7.6
30	6.6	6.6	6.5
	Load Rate (% waste wet/soil dry) 0.7%		
0	7.6	7.6	7.6
30	6.7	6.7	6.7
	Load Rate (% waste wet/soil dry) 1.0%		
0	7.6	7.6	7.6
30	6.7	6.7	6.7
	Control		
0	7.5	7.6	7.6
30	6.5	6.3	6.4

TABLE A-68. RESULTS FOR PH VALUES WITH INCUBATION TIME AT LOW SOIL MOISTURE CONTENT FOR PCP WASTE MIXED WITH DURANT CLAY LOAM SOIL

Sample Time (day)	pH Values Replicate Reactors 1	2	3
	Load Rate (% waste wet/soil dry) 0.3%		
0	6.9	6.8	6.7
28	6.7	6.7	6.5
234	7.4	7.3	7.4
	Load Rate (% waste wet/soil dry) 0.5%		
0	6.9	6.8	6.7
28	6.7	6.7	6.5
234	7.1	7.3	7.1
	Load Rate (% waste wet/soil dry) 0.7%		
0	6.9	6.8	6.7
28	6.7	6.7	6.5
234	7.3	7.1	6.8
	Control		
0	6.9	6.7	6.7
28	6.8	6.5	6.5
234	7.1	6.9	7.1

TABLE A- 69. RESULTS FOR PH VALUES WITH INCUBATION TIME AT LOW SOIL MOISTURE CONTENT FOR PCP WASTE MIXED WITH KIDMAN SANDY LOAM SOIL

Sample Time (day)	pH Values Replicate Reactors 1	 2	 3
	Load Rate (% waste wet/soil dry) 0.075%		
0	7.7	7.6	7.5
28	7.3	7.4	7.4
207	8.3	7.4	7.4
	Load Rate (% waste wet/soil dry) 0.15%		
0	7.7	7.6	7.6
28	7.4	7.4	7.4
207	8.5	8.2	8.2
	Load Rate (% waste wet/soil dry) 0.3%		
0	7.6	7.6	7.6
28	7.4	7.4	7.4
207	8.2	7.1	7.3
	Control		
0	7.7	7.6	7.5
28	7.4	7.4	7.4
207	8.3	7.6	7.5

TABLE A-70. RESULTS FOR PH VALUES WITH INCUBATION TIME AT LOW SOIL MOISTURE CONTENT FOR API SEPARATOR SLUDGE WASTE MIXED WITH DURANT CLAY LOAM SOIL

Sample Time (day)	pH Values Replicate Reactors 1	 2	 3
	Load Rate (% waste wet/soil dry) 6%		
0	7.0	6.8	6.9
37	7.0	7.0	6.8
234	7.1	7.2	6.7
	Load Rate (% waste wet/soil dry) 9%		
0	7.0	6.9	6.8
37	7.2	7.1	7.0
234	7.1	7.3	7.1
	Load Rate (% waste wet/soil dry) 12%		
0	7.3	7.3	7.0
37	7.2	7.2	7.1
234	7.0	7.2	7.1
	Control		
0	6.9	7.1	6.4
37	6.9	6.6	6.5

TABLE A-71 . RESULTS FOR PH VALUES WITH INCUBATION TIME AT LOW SOIL MOISTURE CONTENT FOR API SEPARATOR SLUDGE WASTE MIXED WITH KIDMAN SANDY LOAM SOIL

Sample Time (day)	pH Values Replicate Reactors 1	 2	 3
	Load Rate (% waste wet/soil dry) 6%		
0	7.8	7.6	7.8
29	7.0	7.0	6.9
	Load Rate (% waste wet/soil dry) 9%		
0	7.7	7.7	7.7
29	7.0	7.0	7.0
	Load Rate (% waste wet/soil dry) 12%		
0	7.6	7.6	7.7
29	7.1	7.0	7.0
	Control		
0	7.6	7.5	7.5
29	6.7	6.5	6.6

TABLE A-72 . RESULTS FOR PH VALUES WITH INCUBATION TIME AT LOW SOIL MOISTURE CONTENT FOR SLOP OIL WASTE MIXED WITH DURANT CLAY LOAM SOIL

Sample Time (day)	pH Replicate Reactors 1	 2	 3
	Load Rate (% waste wet/soil dry) 8%		
0	6.1	6.1	6.1
28	6.6	6.6	6.5
	N/A*	6.7	7.0
	Load Rate (% waste wet/soil dry) 12%		
0	6.2	6.1	6.1
28	6.6	6.6	6.6
	Load Rate (% waste wet/soil dry) 14%		
0	6.2	6.2	6.2
28	6.7	6.6	6.6
	Control		
0	6.1	6.1	6.0
28	6.5	6.5	6.4

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*N/A - no analysis.

TABLE A-73. RESULTS FOR PH VALUES WITH INCUBATION TIME AT LOW SOIL MOISTURE CONTENT FOR SLOP OIL WASTE MIXED WITH KIDMAN SANDY LOAM SOIL

Sample Time (day)	pH		
	Replicate Reactors		
	1	2	3
	Load Rate (% waste wet/soil dry) 6%		
0	6.4 7.8	6.3 7.8	6.3 7.7
	Load Rate (% waste wet/soil dry) 8%		
0	6.7 7.8	6.5 7.8	6.4 7.8
	Load Rate (% waste wet/soil dry) 12%		
0	6.3 7.7	6.6 7.7	6.7 7.8
	Control		
0	6.3 7.6	6.4 7.6	6.4 7.5

TABLE A-74. pH DATA WITH INCUBATION TIME FOR API SEPARATOR SLUDGE WASTE APPLIED AT VARIOUS RATES TO KIDMAN SANDY LOAM SOIL AT 1/3 BAR SOIL MOISTURE

Incubation Time (days)	pH Loading Rates			
	M/M[*]	L/H[+]	N/H[#]	H/NR[**]
0	6.7	7.3	6.6	7.4
35	7.2	7.0	7.6	-[++]
70	7.3	7.2	7.0	7.0
98	7.3	7.6	7.3	-

[*] M/M = originally loaded at medium rate (9%), reloaded at medium rate.
[+] L/H = originally loaded at low rate (6%), reloaded at high rate (12%).
[#] N/H = nonacclimated soil loaded at high rate (12%).
[**] H/NR = originally loaded at high rate (12%), not reloaded.
[++] - = no sample taken.

TABLE A-75. pH DATA WITH INCUBATION TIME FOR SLOP OIL WASTE APPLIED AT VARIOUS RATES TO KIDMAN SANDY LOAM SOIL AT 1/3 BAR SOIL MOISTURE

Incubation Time (days)	pH Loading Rates			
	M/M[*]	L/H[+]	N/H[#]	H/NR[**]
0	6.7	6.9	8.1	6.9
39	7.3	9.0	8.1	-[++]
74	7.3	7.6	7.7	7.6
102	7.4	7.6	7.8	-

[*] M/M = originally loaded at medium rate (8%), reloaded at medium rate.
[+] L/H = originally loaded at low rate (6%), reloaded at high rate (12%).
[#] N/H = nonacclimated soil loaded at high rate (12%).
[**] H/NR = originally loaded at high rate (12%), not reloaded.
[++] - = no sample taken.

TABLE A- 76. pH DATA WITH INCUBATION TIME FOR CREOSOTE WASTE APPLIED AT VARIOUS RATES TO KIDMAN SANDY LOAM SOIL AT 1/3 BAR SOIL MOISTURE

Incubation Time (days)	pH Loading Rates			
	M/M*	L/H^{+}	N/H$^{\#}$	H/NR**
0	7.7	7.7	7.4	8.0
42	8.0	8.9	8.5	-$^{++}$
77	7.5	8.3	8.3	8.2
105	7.6	8.6	7.3	-

*M/M = originally loaded at medium rate (0.7%), reloaded at medium rate.
$^{+}$L/H = originally loaded at low rate (0.4%), reloaded at high rate (1.0%).
$^{\#}$N/H = nonacclimated soil loaded at high rate (1.0%).
**H/NR = originally loaded at high rate (1.0%), not reloaded.
$^{++}$- = no sample taken.

TABLE A-77. pH DATA WITH INCUBATION TIME FOR PCP WASTE APPLIED AT VARIOUS RATES TO KIDMAN SANDY LOAM SOIL AT 1/3 BAR SOIL MOISTURE

Incubation Time (days)	pH Loading Rates			
	M/M*	L/H^{+}	N/H$^{\#}$	H/NR**
0	7.8	7.6	7.7	7.4
39	8.0	8.1	8.6	-$^{++}$
74	8.1	7.1	7.6	7.6
102	8.0	8.3	8.1	-

*M/M = originally loaded at medium rate (0.15%), reloaded at medium rate.
$^{+}$L/H = originally loaded at low rate (0.075%), reloaded at high rate (0.3%).
$^{\#}$N/H = nonacclimated soil loaded at high rate (0.3%).
**H/NR = originally loaded at high rate (0.3%), not reloaded.
$^{++}$- = no sample taken.

TABLE A-78. pH DATA WITH INCUBATION TIME FOR API SEPARATOR SLUDGE WASTE APPLIED AT VARIOUS RATES TO DURANT CLAY LOAM SOIL AT 1 BAR SOIL MOISTURE

Incubation Time (days)	pH Loading Rates	
	M/M*	H/NR+
0	7.1	7.0
35	7.3	-#
70	7.4	7.0
98	7.1	-

*M/M = originally loaded at medium rate (9%), reloaded at medium rate.
+H/NR = originally loaded at high rate (12%), not reloaded.
#- = no sample taken.

TABLE A-79. pH DATA WITH INCUBATION TIME FOR SLOP OIL WASTE APPLIED AT VARIOUS RATES TO DURANT CLAY LOAM SOIL AT 1 BAR SOIL MOISTURE

Incubation Time (days)	pH Loading Rates	
	M/M*	H/NR+
0	7.5	6.8
39	7.1	-#
74	6.6	6.7
102	7.8	-

*M/M = originally loaded at medium rate (12%), reloaded at medium rate.
+H/NR = originally loaded at high rate (14%), not reloaded.
#- = no sample taken.

TABLE A-80. pH DATA WITH INCUBATION TIME FOR CREOSOTE WASTE APPLIED AT VARIOUS RATES TO DURANT CLAY LOAM SOIL AT 1 BAR SOIL MOISTURE

Incubation Time (days)	pH Loading Rates	
	M/M*	H/NR+
0	7.6	7.1
42	8.0	-#
77	7.7	7.9
105	7.6	-

*M/M = originally loaded at medium rate (1.0%), reloaded at medium rate.
+H/NR = originally loaded at high rate (1.3%), not reloaded.
#- = no sample taken.

TABLE A-81. pH DATA WITH INCUBATION TIME FOR PCP WASTE APPLIED AT VARIOUS RATES TO DURANT CLAY LOAM SOIL AT 1 BAR SOIL MOISTURE

Incubation Time (days)	pH Loading Rates	
	M/M*	H/NR+
0	7.3	7.0
39	7.5	-#
74	7.4	7.6
102	8.3	-

*M/M = originally loaded at medium rate (0.5%), reloaded at medium rate.
+H/NR = originally loaded at high rate (0.7%), not reloaded.
#- = no sample taken.

TABLE A-82. pH DATA WITH INCUBATION TIME FOR DURANT CLAY LOAM SOIL CONTROL AT 1 BAR SOIL MOISTURE AND KIDMAN SANDY LOAM SOIL CONTROL AT 1/3 BAR SOIL MOISTURE

Incubation Time (days)	pH	
	Durant Clay Loam	Kidman Sandy Loam
0	7.0	7.9
21	7.4	7.8
46	6.2	8.6
74	7.3	8.8

TABLE A-83. RESULTS FOR TOTAL ORGANIC CARBON ANALYSIS FOR API SEPARATOR SLUDGE WASTE MIXED WITH KIDMAN SANDY LOAM SOIL IMMEDIATELY AFTER WASTE ADDITION

Total Organic Carbon (g C/g soil)					
Replicate Reactors					
1	2	3	$\bar{x}$	SD	CV
		Load Rate (% waste wet/soil dry) 6%			
0.0136	0.0118	0.0111	0.0122	0.0013	10.7
		(Load Rate (% waste wet/soil dry) 9%			
0.0136	0.0155	0.0127	0.0139	0.0014	10.1
		(Load Rate (% waste wet/soil dry) 12%			
0.0164	0.0161	0.0156	0.0160	0.0004	2.5
		Control			
0.0047	0.0055	0.0054	0.0052	0.0004	7.7

TABLE A-84. RESULTS FOR TOTAL ORGANIC CARBON ANALYSIS FOR API SEPARATOR SLUDGE WASTE MIXED WITH DURANT CLAY LOAM SOIL IMMEDIATELY AFTER WASTE ADDITION

Total Organic Carbon (g C/g soil)					
Replicate Reactors					
1	2	3	$\bar{x}$	SD	CV
Load Rate (% waste wet/soil dry) 6%					
0.0385	0.0337	0.0362	0.0361	0.0024	6.7
Load Rate (% waste wet/soil dry) 9%					
0.0326	0.0304	0.0316	0.0315	0.0011	3.5
Load Rate (% waste wet/soil dry) 12%					
0.0361	0.0324	0.0313	0.0333	0.0025	7.5
Control					
0.0292	0.0291	0.0297	0.0293	0.0003	1.0

TABLE A-85. RESULTS FOR TOTAL ORGANIC CARBON ANALYSIS FOR CREOSOTE WASTE MIXED WITH DURANT CLAY LOAM SOIL IMMEDIATELY AFTER WASTE ADDITION

Total Organic Carbon (g C/g soil)					
Replicate Reactors					
1	2	3	$\bar{x}$	SD	CV
Load Rate (% waste wet/soil dry) 0.7%					
0.0295	0.0258	0.0288	0.0280	0.0020	7.1
Load Rate (% waste wet/soil dry) 1.0%					
0.0320	0.0328	0.0317	0.0322	0.0006	1.9
Load Rate (% waste wet/soil dry) 1.3%					
0.0350	0.0321	0.0317	0.0329	0.0018	5.5
Control					
0.0263	0.0281	0.0261	0.0268	0.0011	4.1

TABLE A-86. RESULTS FOR TOTAL ORGANIC CARBON ANALYSIS FOR CREOSOTE WASTE MIXED WITH KIDMAN SANDY LOAM SOIL IMMEDIATELY AFTER WASTE ADDITION

Total Organic Carbon (g C/g soil)					
Replicate Reactors					
1	2	3	$\bar{x}$	SD	CV
Load Rate (% waste wet/soil dry) 0.4%					
0.0058	0.0074	0.0059	0.0064	0.0009	14.1
Load Rate (% waste wet/soil dry) 0.7%					
0.0078	0.0080	0.0075	0.0078	0.0003	3.9
Load Rate (% waste wet/soil dry) 1.0%					
0.0078	0.0080	0.0075	0.0078	0.0003	3.9
Control					
0.0048	0.0048	0.0046	0.0047	0.0001	2.1

TABLE A-87. TOXICITY OF WATER SOLUBLE FRACTION MEASURED BY THE MICROTOX ASSAY WITH INCUBATION TIME AT LOW MOISTURE CONTENT FOR API SEPARATOR SLUDGE MIXED WITH DURANT CLAY LOAM SOIL

Sample time (days)	EC50(5,15°)* (Vol %)+					
	Loading Rate (% waste wet wt./soil dry wt.)					
	6%	SD	9%	SD	12%	SD
0	NT#	0	89.8	17.7	73.3	27.1
34	53.0	6.6	86.0	24.3	41.2**	16.2
167	27.7	4.1	26.0	3.0	27.9**	5.4
234	29.4**	4.0	30.5**	0	21.1	5.3

*EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.

+Results given are means of three replicates.

#NT = no apparent toxic effect.

**Mean of two replicates.

TABLE A-88. TOXICITY OF WATER SOLUBLE FRACTION MEASURED BY THE MICROTOX ASSAY WITH INCUBATION TIME AT LOW MOISTURE CONTENT FOR SLOP OIL WASTE MIXED WITH DURANT CLAY LOAM SOIL

Sample time (days)	EC50(5,15°)* (Vol %)+					
	Loading Rate (% waste wet wt./soil dry wt.)					
	8%	SD	12%	SD	14%	SD
0	6.3#	0.6	4.9	2.8	4.1	1.5
129	14.2	3.8	12.8	1.5	10.5	3.8
196	7.2	3.2	8.8	1.8	7.9	3.1

*EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.

+Results given are means of three replicates.

#Mean of two replicates.

TABLE A-89 . TOXICITY OF WATER SOLUBLE FRACTION MEASURED BY THE MICROTOX ASSAY WITH INCUBATION TIME AT LOW SOIL MOISTURE CONTENT FOR CREOSOTE WASTE MIXED WITH DURANT CLAY LOAM SOIL

Sample time (days)	EC50(5,15°)* (Vol %)+					
	Loading Rate (% waste wet wt./soil dry wt.)					
	0.7%	SD	1.0%	SD	1.3%	SD
0	7.0	2.2	6.2	0.8	7.9	0.3
37	12.6	2.0	11.2	0.7	9.7	3.0
167	13.5	7.2	7.5	1.6	8.4	4.7
234	11.7	7.2	3.5#	1.1	5.5	2.9

*EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.
+Results given are means of three replicates.
#Mean of two replicates.

TABLE A-90 . TOXICITY OF WATER SOLUBLE FRACTION MEASURED BY THE MICROTOX ASSAY WITH INCUBATION TIME AT LOW SOIL MOISTURE CONTENT FOR PCP WASTE MIXED WITH DURANT CLAY LOAM SOIL

Sample time (days)	EC50(5,15°)* (Vol %)+					
	Loading Rate (% waste wet wt./soil dry wt.)					
	0.3%	SD	0.5%	SD	0.7%	SD
0	7.7#	1.5	4.8	2.9	3.8#	0.1
140	43.0#	34.5	23.2	15.9	7.9	1.4
207	36.3	30.0	12.9	4.7	6.7	2.8

*EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.
+Results given are means of three replicates.
#Mean of two replicates.

TABLE A- 91 . TOXICITY OF WATER SOLUBLE FRACTION MEASURED BY THE MICROTOX ASSAY WITH INCUBATION TIME AT LOW MOISTURE CONTENT FOR API SEPARATOR SLUDGE MIXED WITH KIDMAN SANDY LOAM SOIL

Sample time (days)	EC50(5,15°)* (Vol %)$^{+}$					
	Loading Rate (% waste wet wt./soil dry wt.)					
	6%	SD	9%	SD	12%	SD
0	76.2	21.5	89.6	18.0	82.1	15.8
29	57.2	37.3	65.9	24.9	33.0	19.3
158	25.9	11.2	29.6	10.6	21.2	2.1
225	15.8#	4.5	19.2	3.2	14.6	3.5

*EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.

$^{+}$Results given are means of three replicates.

#Mean of two replicates.

TABLE A- 92 . TOXICITY OF WATER SOLUBLE FRACTION MEASURED BY THE MICROTOX ASSAY WITH INCUBATION TIME AT LOW MOISTURE CONTENT FOR SLOP OIL MIXED WITH KIDMAN SANDY LOAM SOIL

Sample time (days)	EC50(5,15°)* (Vol %)$^{+}$					
	Loading Rate (% waste wet wt./soil dry wt.)					
	6%	SD	8%	SD	12%	SD
0	5.5	1.7	3.8	0.3	3.6	2.0
131	11.4	1.6	11.6	0.3	8.8	1.2
208	7.2	3.4	9.8#	1.6	7.1	0.9

*EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.

$^{+}$Results given are means of three replicates.

#Mean of two replicates.

TABLE A-93. TOXICITY OF WATER SOLUBLE FRACTION MEASURED BY THE MICROTOX ASSAY WITH INCUBATION TIME AT LOW SOIL MOISTURE CONTENT FOR CREOSOTE WASTE MIXED WITH KIDMAN SANDY LOAM SOIL

Sample time	EC50(5,15°)* (Vol %)+					
	Loading Rate (% waste wet wt./soil dry wt.)					
(days)	0.4%	SD	0.7%	SD	1.0%	SD
0	6.0	1.8	5.4	0.8	4.0	1.3
29	5.0	2.4	3.6	0.4	2.6	0.6
158	6.0	1.0	4.5	1.1	2.8	0.5
225	5.2	1.8	3.3	0.1	4.4	0.8

*EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.
+Results given are means of three replicates.

TABLE A-94. TOXICITY OF WATER SOLUBLE FRACTION MEASURED BY THE MICROTOX ASSAY WITH INCUBATION TIME AT LOW SOIL MOISTURE CONTENT FOR PCP WASTE MIXED WITH KIDMAN SANDY LOAM SOIL

Sample time	EC50(5,15°)* (Vol %)+					
	Loading Rate (% waste wet wt./soil dry wt.)					
(days)	0.075%	SD	0.15%	SD	0.3%	SD
0	5.8	0.8	3.4	0.6	2.3	0.6
140	14.6	8.1	8.4	3.9	4.5	1.8
207	17.2	10.1	6.7	0.6	3.8	0.8

*EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.
+Results given are means of three replicates

TABLE A-95. MICROTOX DATA WITH INCUBATION TIME FOR API SEPARATOR SLUDGE WASTE REAPPLIED AT VARIOUS RATES TO DURANT CLAY LOAM SOIL AT 1 BAR SOIL MOISTURE

Incubation Time (days)	EC50(5,15°)* (vol %) Loading Rates	
	M/M+	H/NR#
0	28.1	35.5
35	27.8	-**
70	21.5	46.3
98	27.0	-

*EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.
+M/M = originally loaded at medium rate (9%), reloaded at medium rate.
#H/NR = originally loaded at high rate (12%), not reloaded.
**- = no sample taken.

TABLE A-96. MICROTOX DATA WITH INCUBATION TIME FOR SLOP OIL WASTE REAPPLIED AT VARIOUS RATES TO DURANT CLAY LOAM SOIL AT 1 BAR SOIL MOISTURE

Incubation Time (days)	EC50(5,15°)* (vol %) Loading Rates	
	M/M+	H/NR#
0	18.3	23.0**
39	9.9	-++
74	3.8	8.6
102	3.5	-

*EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.
+M/M = originally loaded at medium rate (12%), reloaded at medium rate.
#H/NR = originally loaded at high rate (14%), not reloaded.
**Estimated results.
++- = no sample taken.

TABLE A-97. MICROTOX DATA WITH INCUBATION TIME FOR CREOSOTE WASTE REAPPLIED AT VARIOUS RATES TO DURANT CLAY LOAM SOIL AT 1 BAR SOIL MOISTURE

Incubation Time (days)	EC50(5,15°)[*] (vol %) Loading Rates	
	M/M[+]	H/NR[#]
0	13.7	26.0
42	19.6	-[**]
77	7.4	17.5
105	8.5	-

[*] EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.

[+] M/M = originally loaded at medium rate (1.0%), reloaded at medium rate.

[#] H/NR = originally loaded at high rate (1.3%), not reloaded.

[**] - = no sample taken.

TABLE A-98. MICROTOX DATA WITH INCUBATION TIME FOR PCP WASTE REAPPLIED AT VARIOUS RATES TO DURANT CLAY LOAM SOIL AT 1 BAR SOIL MOISTURE

Incubation Time (days)	EC50(5,15°)[*] (vol %) Loading Rates	
	M/M[+]	H/NR[#]
0	13.7	20.9
39	14.8[**]	-[++]
74	4.5[##]	11.7
102	7.0[***]	-

[*] EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.

[+] M/M = originally loaded at medium rate (0.5%), reloaded at medium rate.

[#] H/NR = originally loaded at high rate (0.7%), not reloaded.

[**] Duplicate sample EC50 = 16.0.

[++] - = no sample taken.

[##] Duplicate sample EC50 = 4.8.

[***] Duplicate sample EC50 = 5.3.

TABLE A- 99. MICROTOX DATA WITH INCUBATION TIME FOR API SEPARATOR SLUDGE WASTE REAPPLIED AT VARIOUS RATES TO KIDMAN SANDY LOAM SOIL AT 1/3 BAR SOIL MOISTURE

Incubation Time (days)	EC50(5,15°)* (vol %) Loading Rates			
	M/M+	L/H#	N/H**	H/NR++
0	45.2##	36.0	23.8	33.6
35	30.5	18.8	22.5***	-+++
70	17.1###	10.1****	15.8	18.3
98	21.4	12.7	18.8	-

*EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.
+M/M = originally loaded at medium rate (9%), reloaded at medium rate.
#L/H = originally loaded at low rate (6%), reloaded at high rate (12%).
**N/H = nonacclimated soil loaded at high rate (12%).
++H/NR = originally loaded at high rate (12%), not reloaded.
##Estimated results.
***Duplicate sample EC50 = 29.6.
+++- = no sample taken.
###Duplicate sample EC50 = 18.7.
****Duplicate sample EC50 = 10.1.

TABLE A-100. MICROTOX DATA WITH INCUBATION TIME FOR SLOP OIL WASTE REAPPLIED AT VARIOUS RATES TO KIDMAN SANDY LOAM SOIL AT 1/3 BAR SOIL MOISTURE

Incubation Time (days)	EC50(5,15°)* (vol %) Loading Rates			
	M/M+	L/H#	N/H**	H/NR++
0	17.0	16.0	21.4	16.8++
39	8.0	14.6##	15.5##	-***
74	4.9	3.2	6.2	6.8
102	6.9	4.9+++	4.5	-

*EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.
+M/M = originally loaded at medium rate (8%), reloaded at medium rate.
#L/H = originally loaded at low rate (6%), reloaded at high rate (12%).
**N/H = nonacclimated soil loaded at high rate (12%).
++H/NR = originally loaded at high rate (12%), not reloaded.
##Estimated results.
***- = no sample taken.
+++Duplicate sample EC50 = 3.4.

TABLE A-101. MICROTOX DATA WITH INCUBATION TIME FOR CREOSOTE WASTE REAPPLIED AT VARIOUS RATES TO KIDMAN SANDY LOAM SOIL AT 1/3 BAR SOIL MOISTURE

Incubation Time (days)	EC50(5,15°)* (vol %) Loading Rates			
	M/M+	L/H#	N/H**	H/NR++
0	11.6	11.8	12.9	19.2
42	13.5	11.9	15.9	-##
77	3.1	5.4	5.5	3.7***
105	2.8+++	3.2###	4.9	-

*EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.

+M/M = originally loaded at medium rate (0.7%), reloaded at medium rate.

#L/H = originally loaded at low rate (0.4%), reloaded at high rate (1.0%).

**N/H = nonacclimated soil loaded at high rate (1.0%).

++H/NR = originally loaded at high rate (1.0%), not reloaded.

##- = no sample taken.

***Duplicate sample EC50 = 2.9.

+++Duplicate sample EC50 = 2.7.

###Duplicate sample EC50 = 2.7.

TABLE A-102. MICROTOX DATA WITH INCUBATION TIME FOR PCP WASTE REAPPLIED AT VARIOUS RATES TO KIDMAN SANDY LOAM SOIL AT 1/3 BAR SOIL MOISTURE

Incubation Time (days)	EC50(5,15°)* (vol %) Loading Rates			
	M/M+	L/H#	N/H**	H/NR++
0	12.8	12.7	18.6	23.3
39	17.1	14.4	16.7	-##
74	6.6	3.8	5.3	11.1
102	7.9	5.5	4.4	-

*EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.
+M/M = originally loaded at medium rate (0.15%), reloaded at medium rate.
#L/H = originally loaded at low rate (0.075%), reloaded at high rate (0.3%).
**N/H = nonacclimated soil loaded at high rate (0.3%).
++H/NR = originally loaded at high rate (0.3%), not reloaded.
##- = no sample taken.

TABLE A-103. MICROTOX DATA WITH INCUBATION TIME FOR DURANT CLAY LOAM SOIL CONTROL AT 1 BAR SOIL MOISTURE AND KIDMAN SANDY LOAM SOIL CONTROL AT 1/3 BAR SOIL MOISTURE

Incubation Time (days)	EC50(5,15°)* (vol %)	
	Durant Clay Loam	Kidman Sandy Loam
0	NT+	NT
21	NA#	NT
46	NT	NT
74	NT	NT

*EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.

+NT = no apparent toxic effect.

#NA = no analysis.

TABLE A-104. IMMOBILIZATION OF API SEPARATOR SLUDGE WASTE AS DETERMINED BY MICROTOX BIOASSAY EVALUATION OF LABORATORY COLUMN LEACHATE IMMEDIATELY AFTER WASTE INCORPORATION INTO SOIL

Volume of Leachate (column volumes)	Durant Clay Loam Loading Rate 12% (% waste wet wt/soil dry wt)			Kidman Sandy Loam Loading Rate 12% (% waste wet wt/soil dry wt)		
	EC50(5,15°)[*] (vol%)			EC50(5,15°) (vol %)		
	Replicate 1	Replicate 2	Avg.[+]	Replicate 1	Replicate 2	Avg.
1	33.7	6.5	20.1	NT[#]	NT	NT
3	NT	NA[**]	NT	NT	NA	NT
5	NT	64.4	-	NT	NT	NT
7	NT	NA	NT	NT	NA	NT
9	NT	NT	NT	NT	89.6	-
11	90.6	96.3	93.5	NT	57.4	-
13	56.9	NT	-	NT	66.9	-
15	61.4	93.9	77.7	NT	NT	NT

[*] EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.

[+] Avg. = average value based on two replicates.

[#] NT = no apparent toxic effect.

[**] NA = no analysis.

TABLE A-105. IMMOBILIZATION OF SLOP OIL EMULSION SOLIDS WASTE AS DETERMINED BY MICROTOX BIOASSAY EVALUATION OF LABORATORY COLUMN LEACHATE IMMEDIATELY AFTER WASTE INCORPORATION INTO SOIL

Volume of Leachate (column volumes)	Durant Clay Loam Loading Rate 14% (% waste wet wt/soil dry wt)			Kidman Sandy Loam Loading Rate 12% (% waste wet wt/soil dry wt)		
	EC50(5,15°)* (vol%)			EC50(5,15°) (vol %)		
	Replicate 1	Replicate 2	Avg.+	Replicate 1	Replicate 2	Avg.
1	NT#	NT	NT	NT	NT	NT
3	NT	NA**	NT	59.1	NA	59.1
5	NT	59.2	-	NT	NA	NT
7	NT	NA	NT	NT	NA	NT
9	NT	90.3	-	NT	83.3	-
11	NT	NA	NT	NT	NA	NT
13	NT	86.0	-	NT	NT	NT
15	NT	NA	NT	NT	NA	NT

*EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.
+Avg = average value based on two replicates.
#NT = no apparent toxic effect.
**NA = no analysis.

TABLE A-106. IMMOBILIZATION OF CREOSOTE WASTE AS DETERMINED BY MICROTOX BIOASSAY EVALUATION OF LABORATORY COLUMN LEACHATE IMMEDIATELY AFTER WASTE INCORPORATION INTO SOIL

Volume of Leachate (column volumes)	Durant Clay Loam Loading Rate 1.3% (% waste wet wt/soil dry wt)			Kidman Sandy Loam Loading Rate 1.0% (% waste wet wt/soil dry wt)		
	EC50(5,15°)* (vol%)			EC50(5,15°) (vol %)		
	Replicate 1	Replicate 2	Avg.⁺	Replicate 1	Replicate 2	Avg.
1	NT#	NT	NT	43.0	NA**	43.0
3	91.6	NA	91.6	16.0	NA	16.1
5	56.9	67.4	62.2	17.7	22.6	20.2
7	NT	NA	NT	46.7	NA	46.7
9	83.7	66.5	75.1	77.5	12.5	45.0
11	NT	NA	NT	45.5	NA	45.5
13	NT	59.1	-	64.3	32.8	48.5
15	NT	NA	NT	86.3	NA	86.3

*EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.

⁺Avg = average value based on two replicates.

#NT = no apparent toxic effect.

**NA = no analysis.

TABLE A-107. IMMOBILIZATION OF PCP WASTE AS DETERMINED BY MICROTOX BIOASSAY EVALUATION OF LABORATORY COLUMN LEACHATE IMMEDIATELY AFTER WASTE INCORPORATION INTO SOIL

Volume of Leachate (column volumes)	Durant Clay Loam Loading Rate 0.7% (% waste wet wt/soil dry wt)			Kidman Sandy Loam Loading Rate 0.3% (% waste wet wt/soil dry wt)		
	EC50(5,15°)* (vol%)			EC50(5,15°) (vol %)		
	Replicate 1	Replicate 2	Avg.+	Replicate 1	Replicate 2	Avg.
1	NT#	NT	NT	NT	23.7	-
3	NT	NT	NT	7.3	NA**	7.3
5	47.4	NT	-	70.9	47.0	59.0
7	NT	NA	NT	23.3	NA	23.0
9	34.9	23.2	29.1	NT	60.8	-
11	31.0	NA	31.0	NT	NA	NT
13	27.6	24.2	25.9	NT	NT	NT
15	35.5	NA	35.5	NT	NA	NT

*EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.

+Avg = average value based on two replicates.

#NT = no apparent toxic effect.

**NA = no analysis.

TABLE A-108. IMMOBILIZATION OF API SEPARATOR SLUDGE WASTE AS DETERMINED BY MICROTOX BIOASSAY EVALUATION OF LABORATORY COLUMN LEACHATE 352 DAYS AFTER WASTE INCORPORATION INTO SOIL

Volume of Leachate (column volumes)	Durant Clay Loam Loading Rate 12% (% waste wet wt/soil dry wt) EC50(5,15°)[*] (vol %)	Kidman Sandy Loam Loading Rate 12% (% waste wet wt/soil dry wt) EC50(5,15°) (vol %)
1	68.3	36.0
3	NT[+]	14.9
5	78.0	81.3
7	NT	45.4

[*] EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.

[+] NT = no apparent toxic effect.

TABLE A-109. IMMOBILIZATION OF SLOP OIL EMULSION SOLIDS AS DETERMINED BY MICROTOX BIOASSAY EVALUATION OF LABORATORY COLUMN LEACHATE 323 DAYS AFTER WASTE INCORPORATION INTO SOIL

Volume of Leachate (column volumes)	Durant Clay Loam Loading Rate 14% (% waste wet wt/soil dry wt) EC50(5,15°)[*] (vol %)	Kidman Sandy Loam Loading Rate 12% (% waste wet wt/soil dry wt) EC50(5,15°) (vol %)
1	74.9	NT[+]
3	NT	60.7
5	NT	48.8
7	31.2	97.1

[*] EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.

[+] NT = no apparent toxic effect.

TABLE A-110. IMMOBILIZATION OF CREOSOTE WASTE AS DETERMINED BY MICROTOX BIOASSAY EVALUATION OF LABORATORY COLUMN LEACHATE 361 DAYS AFTER WASTE INCORPORATION INTO SOIL

Volume of Leachate (column volumes)	Durant Clay Loam Loading Rate 1.3% (% waste wet wt/soil dry wt) EC50(5,15^o)* (vol %)	Kidman Sandy Loam Loading Rate 1.0% (% waste wet wt/soil dry wt) EC50(5,15^o) (vol %)
2	58.6	NT+
3	48.2	31.3
5	NT	21.9
7	NT	26.3

*EC50(5,15^o) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15^{o}C.
+NT = no apparent toxic effect.

TABLE A-111. IMMOBILIZATION OF PCP WASTE AS DETERMINED BY MICROTOX BIOASSAY EVALUATION OF LABORATORY COLUMN LEACHATE 334 DAYS AFTER WASTE INCORPORATION INTO SOIL

Volume of Leachate (column volumes)	Durant Clay Loam Loading Rate 0.7% (% waste wet wt/soil dry wt) EC50(5,15^o)* (vol %)	Kidman Sandy Loam Loading Rate 0.3% (% waste wet wt/soil dry wt) EC50(5,15^o) (vol %)
1	NT+	60.7
3	63.3	27.0
5	NT	73.9
7	56.8	80.3

*EC50(5,15^o) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15^{o}C.
+NT = no apparent toxic effect.

TABLE A-112. MICROTOX RESULTS WITH INCUBATION TIME FOR DURANT CLAY LOAM SOIL CONTROL AT 1 BAR SOIL MOISTURE AND KIDMAN SANDY LOAM SOIL CONTROL AT 1/3 BAR SOIL MOISTURE

Incubation Time (days)	EC50(5,15°)* (vol %)	
	Durant Clay Loam	Kidman Sandy Loam
0	NT+	NT
21	NA#	NT
46	NT	NT
74	NT	NT

*EC50(5,15°) denotes the conditions for the test, i.e., reading light output 5 minutes after sample addition at a temperature of 15°C.
+NT = no apparent toxic effect.
#NA = no analysis.

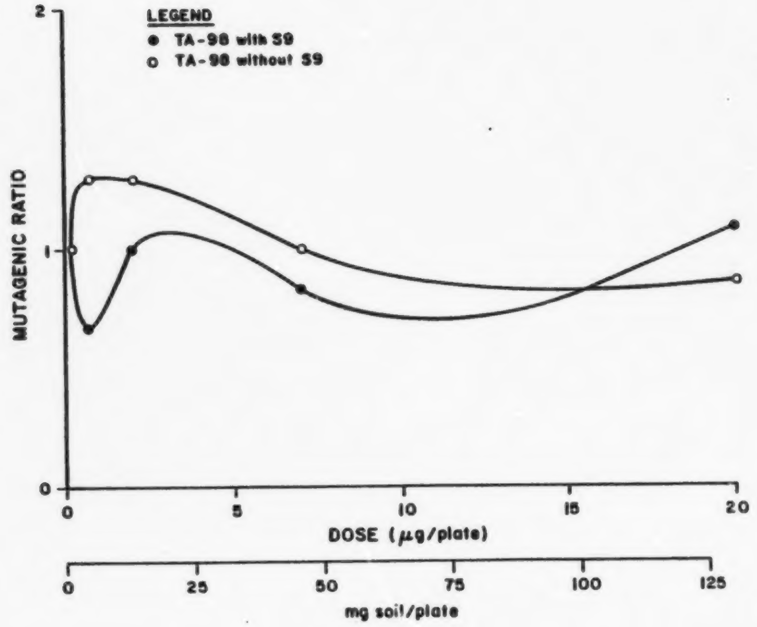

Figure A-1. Ames assay results for Durant clay loam.

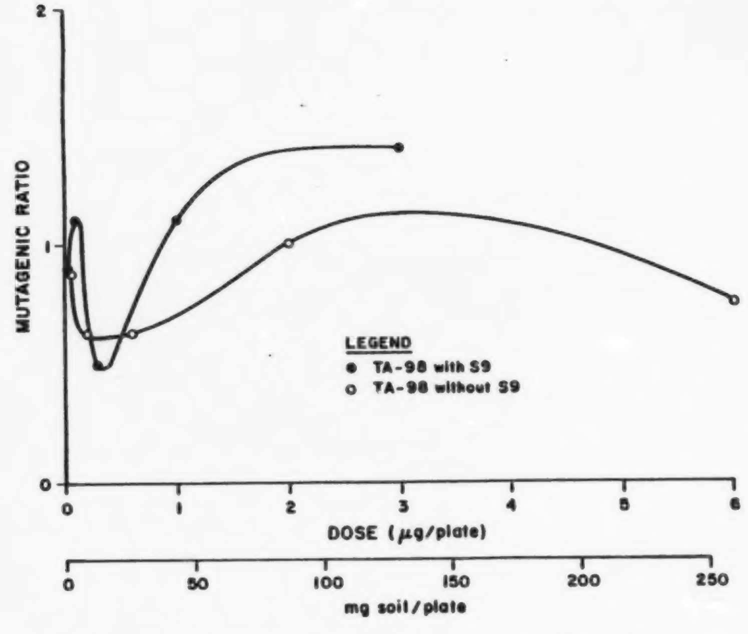

Figure A-2. Ames assay results for Kidman sandy loam.

APPENDIX B

PREDICTIVE TOOL FOR SOIL-WASTE PROCESSES

INTRODUCTION

Mathematical models can be utilized to provide a rational approach for obtaining, organizing, and evaluating specific information required for soil-waste systems. A relevant model can be considered as a tool for integrating data concerning contaminant transformation, immobilization, and degradation for assessing the relative treatment effectiveness of alternative design/ management combinations. The multiple factors involved in determining the success of treatment are generally complex and make it difficult to evaluate the effect of each factor on the total treatment process without a tool for interrelating these individual factors. A model also can be used to guide the design of specific experiments and the collecion of specific data. Specifically, the effects of design and operating alternatives on the soil site assimilative capacity (SSAC) may be predicted, and the influence of waste type and soil type on treatment may be assessed.

A mathematical description of the soil-waste system site assimilative capacity system provides a unifying framework for the evaluation of laboratory screening and field data that is useful for the determination of treatment for a waste. While current models cannot be relied upon for long-term predictions of absolute contaminant concentrations due to the lack of an understanding of the biological, physical, and chemical complexity of the soil/waste environment, they represent a powerful tool for ranking design, operation, and maintenance alternatives as well as for the design of monitoring programs.

A mathematical description of soil-waste systems provides a framework for:

(1) Evaluation of literature and/or experimental data;

(2) Evaluation of the effects of site characteristics on treatment performance (soil type, soil horizons, soil permeability);

(3) Determination of the effects of loading rate, loading frequency, irrigation, and amendments to increase degradation, on soil treatment performance;

(4) Evaluation of the effects of environmental parameters (season, precipitation) on soil treatment performance; and

(5) Comparison of the effectiveness of treatment using different practices in order to maximize soil treatment.

MODEL DESCRIPTION

The effectiveness of a site for treatment will depend on its ability to immobilize and/or degrade hazardous waste constituents. There are many mechanisms influencing these two phenomena, and although certain characteristics can be identified and quantified independently for specific substances, it is necessary to express the mechanisms in mathematical terms to evaluate the overall performance of a site. The mathematical formulation also facilitates the transfer of knowledge optained at one site to other similar sites.

Short (1985) presented a predictive model (Regulatory and Investigative Treatment Zone model; RITZ) based on the approach by Jury et al. (1983) for simulating the fate of pesticides in soils. The RITZ model has been expanded at Utah State University during this project to incorporate features which increase its utility for the planning and evaluation of treatment for soil-waste systems.

The extended version of the model is programmed for the computer in such a way that additional enhancements (such as unsteady flow and time variable decay transport/partition coefficients) may be incorporated into the model in the future with a minimum of reprogramming. A summary description of the extended RITZ model is provided below. Additional details concerning the model can be obtained in the Permit Guidance Manual on Hazardous Waste Land Treatment Demonstrations (U.S. EPA 1986b).

Model Construct

The model describes a soil column 1 meter square with depth specified by the user. The soil environment within the column is made up of four phases: soil grains, pore water, pore air, and pore oil. It is important that all phases and constituent states be included in order to accurately simulate interactions and maintain a mass balance in the model. Characteristics of the soil environment may change with depth and/or time. The waste is applied to the plow zone at loading rates and frequencies specified by the user.

The constituent is acted on by the transport and degradation mechanisms in the model, and its "life history" is calculated at intervals determined by the user. The constituent may migrate from one phase to another during the course of the model simulation. Breakthrough occurs when a pre-determined concentration level is exceeded at the bottom of the lower treatment zone. The average Soil Retention Time (SRT) and Treatment Efficiency are estimated from the model results.

Immobilization/Transport

A constituent may be mobilized by three mechanisms: migration between/among phases, dispersion, and advection.

Migration--

When two or more phases are in contact, the constituent will tend to migrate between/among them. This mechanism is modeled by assuming that constituent concentrations reach equilibrium immediately between/among all phases which are in contact. This equilibrium condition is described by partition coefficients determined from literature data, laboratory experiments, field sampling, and/or appropriate parameter estimation methods.

The upper zone contains all four phases and the constituents migrate among them to maintain equilibrium. In addition, the oil phase is assumed to decay with first-order kinetics and releases its contents to the other three phases. It is assumed that the oil phase does not penetrate significantly below the upper zone.

Dispersion--

Concentration gradients drive transport within a phase from regions of high concentration to regions of low concentration. Dispersive transport is caused by molecular diffusion and turbulence within the phase. In the model, dispersion is the primary transport mechanism for the volatile fraction of the constituent in the air phase. This mechanism is included in the model because of its importance in distributing the mass of the constituent in the vapor phase throughout the soil column.

Advection--

If a phase moves through the soil column, it will transport the constituent along with it. In the model, the water phase and its dissolved constituents are advected at the average soil pore water velocity. This velocity is calculated from the site infiltration rate and the site soil type.

The movement of the constituent is retarded via adsorption/desorption by the other phases that it comes in contact with as it passes through the soil column.

Constituent Degradation

The constituent may be decomposed by biochemical processes which are represented in the model by first-order rate kinetics. Different rate coefficient values may be assigned to different phases and to different depths within the soil column.

Input

Table B-1 shows specific input parameters characterizing the waste constituents. These parameters may be obtained from laboratory experiments, literature data, and/or parameter estimation techniques used in conjunction with field and laboratory observations.

TABLE B-1. VARIABLES FOR USE IN THE EXTENDED RITZ MODEL

Biodegradation information (for each soil zone as appropriate):
Half-life ($t_{1/2}$) for each constituent of concern, corrected for volatilization

Immobilization information (for each soil zone as appropriate):
Ko = partitioning of constituents between water and oil phases
Kd = partitioning of constituents between water and soil phases
Kh = partitioning of constituents between water and air phases

Output

The user may select the level of detail for the output of the model results. The output may include the constituent concentrations in each phase at selected depths in the soil column, and at times specified by the user. Output also includes the time to breakthrough of the constituent at the bottom of the designated treatment zone at leachate concentrations at or above analytical detection limits for the constituents.

MODEL APPLICATION

The results of the model, representing an integration of laboratory, literature, and/or calculated input data may include the determination of:

1. Maximum residence time of each constituent in the upper zone of soil;

2. Upper zone breakthrough time for constituent concentration at or above the detection limit;

4. Concentration of the constituent in the leachate at breakthrough; Cb, $\geq$ detection limit if available;

5. Retardation factor in a lower zone; and

6. Velocity of the pollutant through a soil zone.